









Digitized by the Internet Archive  
in 2012 with funding from  
University of California, Davis Libraries

<http://archive.org/details/earthquakeplanni61cali>





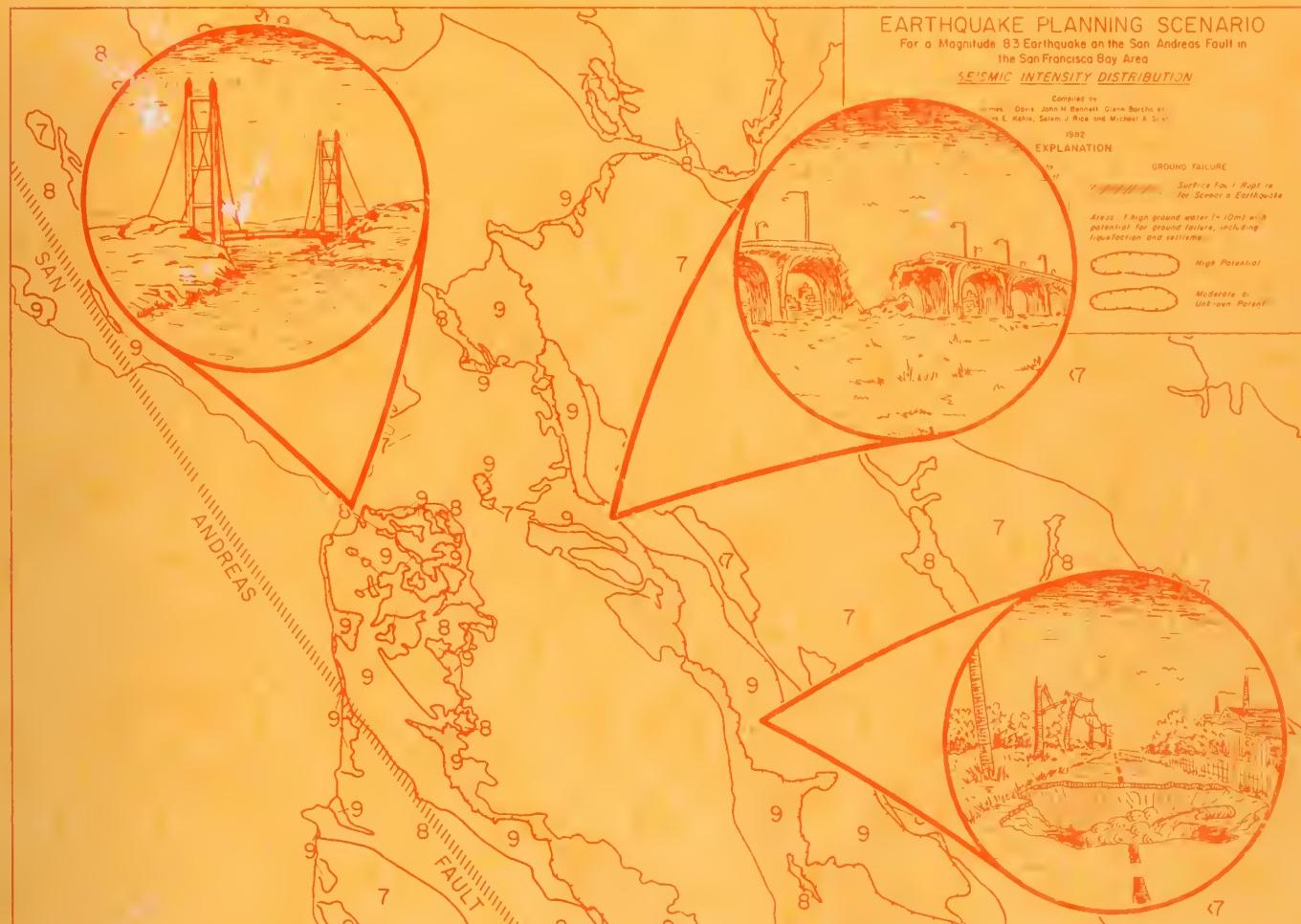
QE C9  
A1  
C32  
n.61

PHYSICAL SCI. LIB.

# EARTHQUAKE PLANNING SCENARIO

S S

For a Magnitude 8.3 Earthquake  
on the San Andreas Fault  
in the San Francisco Bay Area



CALIFORNIA DEPARTMENT OF CONSERVATION  
DIVISION OF MINES AND GEOLOGY



PHYSICAL SCIENCES LIBRARY  
UNIVERSITY OF CALIFORNIA  
DAVIS, CALIFORNIA 95618

SPECIAL PUBLICATION 61



THIS REPORT WAS PREPARED FOR THE  
GOVERNOR'S EMERGENCY TASK FORCE ON EARTHQUAKE PREPAREDNESS  
AND IS FOR EMERGENCY PLANNING PURPOSES ONLY



STATE OF CALIFORNIA  
EDMUND G. BROWN JR.  
*GOVERNOR*

THE RESOURCES AGENCY  
HUEY D. JOHNSON  
*SECRETARY FOR RESOURCES*

DEPARTMENT OF CONSERVATION  
JAN DENTON  
*DIRECTOR*

DIVISION OF MINES AND GEOLOGY  
JAMES F. DAVIS  
*STATE GEOLOGIST*

PHYSICAL SCIENCES LIBRARY  
UNIVERSITY OF CALIFORNIA  
DAVIS, CALIFORNIA 95616

EARTHQUAKE PLANNING SCENARIO  
FOR A MAGNITUDE 8.3 EARTHQUAKE  
ON THE SAN ANDREAS FAULT IN THE SAN FRANCISCO BAY AREA

By

James F. Davis, John H. Bennett, Glenn A. Borchardt,  
James E. Kahle, Salem J. Rice, and Michael A. Silva

1982

California Department of Conservation  
Division of Mines and Geology

Special Publication 61

Prepared for the Governor's Emergency Task Force  
on Earthquake Preparedness



PREFATORY COMPARISON  
OF THE NORTHERN AND SOUTHERN CALIFORNIA  
EARTHQUAKE PLANNING SCENARIOS FOR THE SAN ANDREAS FAULT

To be effective, emergency-response plans must reflect the general consequences of an anticipated earthquake within a particular region. Therefore, emergency-response plans are not checklists of generalized conditions that must be dealt with; rather they are systematic strategies that are closely related to the special circumstances of the area for which they are designed. The emergency-response plans required to be effective in coping with a northern California magnitude 8.3 earthquake on the San Andreas fault are significantly different from those appropriate to a similar sized earthquake on the southern California segment. This planning insight is evident from a comparison of Special Publication 60 (southern California) and Special Publication 61 (northern California), two planning scenarios that have been developed by the California Division of Mines and Geology (CDMG). Since these scenarios are identical in scientific approach and methodology, genuine contrasts between patterns of regional consequences can be identified.

The discussion which follows highlights the principal contrasts between the effects of magnitude 8.3 earthquakes on the San Andreas fault segments in the vicinity of Los Angeles and of San Francisco. These scenario earthquakes

will be similar in size and location to the 1857 earthquake in southern California and the 1906 earthquake in northern California.

The general consequences of these scenario earthquakes in both southern and northern California will be to overwhelm existing capabilities of coping with significant interruption of ground transportation, communications, water supply, sewage treatment, electricity, and pipeline distribution of natural gas and petroleum. Existing emergency-response capabilities will be taxed beyond their limits by the combined effect of regional damage to all the important lifelines upon which the metropolitan areas depend. These circumstances will compound the problem of providing medical aid and search-and-rescue services to the stricken areas.

In southern California, the strategy for bringing supplies and assistance into the Los Angeles region following the earthquake should emphasize ground transportation, which will probably be possible by freeway and by railroad from San Diego. In addition, air transport into the area will be feasible for large cargo planes at a number of the large airfields if auxiliary power supplies are available to maintain radio communications, landing lights, and other requirements necessary to the operation. An effective distribution of materiel and personnel within this large metropolitan region will be a greater challenge than access to the region from the outside. A major handicap to the effort to coordinate this distribution will be the extensive loss of hard-wire communications within the area during the first 72 hours after the earthquake. Marine transport may supplement access to the area, but principal

shipment will be by ground and air. Law enforcement in the southern California area will have to cope with significant variations in the extent of damage, and law enforcement procedures should be oriented to regulating ground-transportation access into stricken areas and to preventing the intrusion of sight-seers, looters, and other undesirables.

In the northern study area, the San Andreas fault is nearer the urban regions and approximately parallels highway corridors that traverse the San Francisco peninsula connecting the city to other urban and suburban centers. Ground transportation by highway and rail will be severely affected for portions or all of the 72 hours immediately following the magnitude 8.3 earthquake. Air transportation facilities capable of accommodating large cargo planes cannot be counted upon to be in service within the Bay area. The closest usable airfields may be Buchanan near Concord and Travis near Vacaville. Only helicopter transport can be counted upon to bring medical and other needed aid and supplies into the stricken area from the outside. This means that a detailed coordination must be made between helicopter landing sites and modes of distributing the off-loaded material within the stricken area. Priorities must be established for the types and amounts of material which can be safely delivered from the outside. The feasibility of extensive marine transportation should be evaluated as a principal means of bringing personnel and materiel into the region. Loss of electrical power, water, hard-wire communications, and other support lifelines will greatly complicate the emergency-response process and must be provided for in the planning.

Emergency planners should be aware that plans which should be developed for the northern and southern scenario earthquakes will necessarily be distinctive and will not be interchangeable. For an effective emergency response, it will be necessary for plans to exist that provide for coordination between all municipalities and jurisdictions in the affected regions. Since some of the lifelines are maintained only by public agencies and others are possessions of the private sector, it is mandatory that plans provide for emergency responses that integrate the efforts of the public and private sectors.

## CONTENTS

	Page
PREFATORY COMPARISON OF NORTHERN AND SOUTHERN CALIFORNIA EARTHQUAKE PLANNING SCENARIOS.....	iii
PURPOSE, APPROACH AND DESIGN OF SCENARIO.....	3
EXECUTIVE SUMMARY.....	9
ACKNOWLEDGMENTS.....	29
INTRODUCTION.....	31
How to Use the Earthquake Planning Scenario Maps.....	32
Limitations of the Earthquake Planning Scenario Maps.....	34
SEISMIC INTENSITY DISTRIBUTION.....	35
Regional Seismic Intensity Investigations, in General.....	36
Development of the Seismic Intensity Distribution Map for this Scenario.....	37
GENERAL CHARACTER OF THE SEISMIC INTENSITY DISTRIBUTION MAP.....	45
EARTHQUAKE PLANNING SCENARIOS FOR LIFELINES IN THE SAN FRANCISCO BAY AREA.....	47
EARTHQUAKE PLANNING SCENARIO: HIGHWAYS.....	49
General Pattern.....	49
Description.....	50
Planning Insights.....	52
Recommended Further Work.....	53
EARTHQUAKE PLANNING SCENARIO: AIRPORTS.....	67
General Pattern.....	67
Description.....	67
Planning Insights.....	69
Recommended Further Work.....	69
EARTHQUAKE PLANNING SCENARIO: RAILROADS.....	75
General Pattern.....	75
Description.....	75
Planning Insights.....	78
Recommended Further Work.....	79

EARTHQUAKE PLANNING SCENARIO: MARINE FACILITIES.....	85
General Pattern.....	85
Description.....	85
Planning Insights.....	88
Recommended Further Work.....	89
EARTHQUAKE PLANNING SCENARIO: COMMUNICATIONS.....	93
General Pattern.....	93
Description.....	94
Telephone Systems.....	94
Radio Systems.....	100
General Comments on the Communications Scenario.....	107
Planning Insights.....	109
Recommended Further Work.....	109
EARTHQUAKE PLANNING SCENARIO: WATER SUPPLY AND WASTE DISPOSAL.....	111
General Pattern.....	111
Description.....	112
Planning Insights.....	121
Recommended Further Work.....	121
EARTHQUAKE PLANNING SCENARIO: ELECTRICAL POWER.....	125
General Pattern.....	125
Description.....	126
Planning Insights.....	132
Recommended Further Work.....	133
EARTHQUAKE PLANNING SCENARIO: NATURAL GAS.....	137
General Pattern.....	137
Description.....	137
Planning Insights.....	139
Recommended Further Work.....	139
EARTHQUAKE PLANNING SCENARIO: PETROLEUM FUELS.....	143
General Pattern.....	143
Description.....	143
Planning Insights.....	145
Recommended Further Work.....	145
GLOSSARY.....	149
REFERENCES.....	151
APPENDIX.....	155

LIST OF  
EARTHQUAKE PLANNING SCENARIO MAPS

<u>Map No.</u>	<u>Subject</u>	<u>Located in Text Following Page</u>
1-S	SEISMIC INTENSITY DISTRIBUTION.....	46
	<u>Lifeline Damage Assessments</u>	
1-HA	HIGHWAYS AND AIRPORTS.....	66
1-RM	RAILROADS AND MARINE FACILITIES.....	83
1-C	COMMUNICATIONS (Telephone Systems).....	110
1-W	WATER SUPPLY AND WASTE DISPOSAL.....	124
1-E	ELECTRICAL POWER.....	136
1-G	NATURAL GAS.....	141
1-P	PETROLEUM FUELS.....	147



EARTHQUAKE PLANNING SCENARIO  
FOR A MAGNITUDE 8.3 EARTHQUAKE ON THE  
SAN ANDREAS FAULT IN THE SAN FRANCISCO BAY AREA



PURPOSE, APPROACH, AND DESIGN  
OF SCENARIO

Perspective: Three great earthquakes of magnitude (M)  $8\pm$  have occurred in California during the state's brief 132-year history, one in Owens Valley (1872) and two along the San Andreas fault (1857 and 1906). Since the most recent of these great earthquakes early in the century, the state has experienced unparalleled growth. As a result, the inevitable, next great earthquake on the San Andreas fault promises to be even more catastrophic than the 1906 event. Many smaller events continue to cause significant damage and loss of life. The 1933 Long Beach and the 1971 San Fernando earthquakes have demonstrated the need for improved construction and institutional practices. State legislation, changes in local policies, and revisions of the Uniform Building Code have since provided for the improvement of these practices.

The prospect of another great earthquake (M 8.0 or greater) on the northern San Andreas fault has been a latent source of concern in public policy over the years. During the mid-1960s earth scientists began to appreciate the dynamics of the earth's crust and to understand the role of the San Andreas and other tectonic plate boundary faults in such movement. This insight has confirmed the inevitability of future great earthquakes on the San Andreas fault. In the mid-1970s, the Palmdale bulge, or southern California uplift, drew attention to active deformation of the earth's crust in the vicinity of the San Andreas fault. Subsequent analyses of geodetic data relating to the uplift and deformation since that time have demonstrated the complexity of such phenomena, but do not modify the prospect of a future great earthquake.

During the late 1970s, K. Sieh explored the history of displacements created by large earthquakes on the south-central San Andreas fault by studying offsets in stratified materials that were exposed in trenches. The results of this work have materially advanced the understanding of the frequency of great earthquakes on the San Andreas fault. A sequence of twelve major events has occurred on this segment of the fault over the past 2,000 years at various intervals ranging between 100 to 200 years, averaging one large event about every 140 years. During this decade we will mark the 130th anniversary of the 1857 event. In comparison, the chronology of large earthquakes on the northern San Andreas fault, the segment that we are concerned with in this scenario, is less certain. However, based on our understanding at this time, it is appropriate to consider that another great earthquake can occur on the northern San Andreas fault sometime during the next several decades and, thus, during the lifetime of many of the residents of the area.

Challenge: Following the eruption of Mount St. Helens, the President requested the National Security Council to consider the implications of the occurrence of a large damaging earthquake in the State of California. The results of this analysis were presented in a report published by the Federal Emergency Management Agency (FEMA) in January 1981. Several conclusions were highlighted.

- o First instance property losses for the M 8.3 event on the northern San Andreas fault are estimated to be close to \$40 billion.
  
- o Depending upon the time of day, this M 8.3 event will kill between 3,000 and 11,000 people and cause between 12,000 and 44,000 people to require hospitalization.

o A survey of local, State, and Federal government emergency plans has indicated that, although there is a general capacity to respond to small- and intermediate-sized earthquakes, it is unlikely that any of these units of government can cope with a great earthquake such as a M 8.3 event on the northern San Andreas fault.

Workers in California generally agree with these conclusions. To California citizens the message is clear. We must anticipate the occurrence of great earthquakes that will overwhelm our present capabilities to respond adequately and in an organized manner, both as a society and as individuals. Such sobering events satisfy the definition of the term "catastrophic" as it is used in this report. The good news is, of course, that appropriate pre-earthquake planning and countermeasures can greatly enhance our capability to respond to these great events.

Response: The conclusions of the National Security Council were communicated to the Governor of California by the President. In response, the Governor's Emergency Task Force on Earthquake Preparedness was established in February 1981. The Task Force chairman, Dr. William W. Whitson, established a group of committees to deal with improvement of emergency-response functions such as communications, management of waste and water, search and rescue, fire fighting and others. A Threat Assessment Committee was also created to characterize the outcome of great earthquakes as a basis for improved emergency-response planning. The Committee is co-chaired by James F. Davis, the California State Geologist, and Karl V. Steinbrugge, structural engineer. Members of the Committee include Rachel Gulliver, Mary C. Woods, Janice Hutton, Roger W. Sherburne, and Dennis S. Miletic.

Scenarios: The January 1981 FEMA report has underscored that the occurrence of a great earthquake on the northern San Andreas fault is a matter which should engender immediate public concern. The Threat Assessment Committee, in conjunction with the chairman of the Task Force, elected to use scenarios to serve as a basis for emergency planning. Selected for scenarios were a M 8.3 event on the northern segment of the San Andreas fault, similar to the event which produced the 1906 San Francisco earthquake, and a M 8.3 event on the south-central segment of this fault similar to the 1857 earthquake in southern California.

The general plan of the Committee is to forecast the physical effects of the northern and southern California scenario earthquakes. An analysis of the ground shaking and ground failure associated with a M 8.3 event on the northern San Andreas fault is presented in this scenario. This information, together with an assessment of the anticipated general damage patterns to lifelines, constitutes the Earthquake Planning Scenario map series included in this report.

Earthquake planning scenarios are intended to portray the probable consequences of catastrophic earthquakes. By this means we communicate the message that it is possible to cope with these natural hazards by personal, corporate, and government efforts in preparedness planning. Hopefully, this report will be constructive to this end. We also intend that it will motivate a commitment to participation because it provides an understanding that planning and action will make a real difference in reducing the dimensions of the disaster.

This planning scenario is intended to contribute to the efforts of the following users:

- o Local, State, and Federal officials with emergency planning responsibilities.
- o Elected officials who must be able to visualize the threat in order to commit themselves to the leadership roles needed to cope with the earthquake.
- o Private-sector leaders and planners who must know about and understand the hazard in order to prepare for it.
- o Educators, journalists, and other public opinion makers who must appreciate the threat and communicate its character in order to motivate citizen commitment to preparedness.
- o The citizens of northern California who must support public mitigation efforts and develop personal strategies for themselves and their families in order to minimize the effects of the earthquake on their lives.

It is reassuring that many of these users are participating in the activities of the Governor's Emergency Task Force on Earthquake Preparedness, which during 1981 and 1982 has numbered between 300 and 400 individuals.



## EXECUTIVE SUMMARY

This scenario portrays anticipated damage to the highway, airport, railway, marine, communication, water, waste disposal, electrical power, natural gas, and petroleum lifelines that service the metropolitan areas of the greater San Francisco Bay area, when this area is subjected to a large (magnitude 8  $\pm$ ) earthquake, an event expected to take place during the lifetime of many of the current residents. The principal challenge in responding to the consequences of this event will be the transport of people and materiel within as well as from outside the stricken region. Emergency preparations should be based upon the assumption that electrical power, communications, water supplies, and sewage treatment facilities will be significantly affected.

Most of the lifelines will experience significant adverse effects, and coping with any one of them would require a major emergency-response effort. The combined impact of all the lifelines being simultaneously impaired by the scenario earthquake greatly escalates the problem. The added strain of dealing with the thousands of deaths and casualties requiring hospitalization that will result from this earthquake will put an unprecedented demand upon government institutions, utilities, businesses, individuals, and society in general. The circumstances will be catastrophic, i.e., they will overwhelm our institutional and personal capacities to cope, unless public awareness and emergency preparedness can provide an adequate means of responding. The information presented in this report is intended to be a basis for such planning and preparedness.

In developing this earthquake planning scenario, the California Division of Mines and Geology (CDMG) assumed the occurrence of a M 8.3 event on the northern segment of the San Andreas fault, similar to the event that produced the April 18, 1906 San Francisco earthquake. A regional intensity map to be employed in the assessment of lifeline damages was prepared using the Evernden computer model (Evernden and others, 1973, 1981) for calculating seismic intensity and based in part on an intensity map published by the U.S. Geological Survey (1981) for the M 8.3 event on the northern San Andreas fault that is addressed in this scenario. CDMG modified this intensity map to reflect more detailed and additional geological information that was not included in Evernden's analysis. On the basis of its inclusion of information on local geology and ground water conditions, CDMG also delineated areas of potential ground failure. Thus, CDMG's SEISMIC INTENSITY DISTRIBUTION map (Map 1-S) shows anticipated intensities for both shaking and ground failure.

Intensity zones are shown on the map as isoseismal areas -- that is, as areas within which the anticipated seismic intensities, or local earthquake effects, are considered comparable. Each intensity zone is assigned an intensity rating based on the Rossi-Forel (R-F) intensity scale (see Appendix).

The areas of predicted intensity 9 (R-F) include most of the low-lying lands surrounding San Francisco and San Pablo Bays. This area of intense shaking encompasses a major portion of the more highly developed urban areas including most of the Santa Clara Valley and portions of San Francisco, Oakland, and virtually all of the other communities that border the Bays. In addition, portions of this area that are situated on Bay mud are susceptible to ground failures. This additional hazard is present in parts of Oakland,

Alameda, Richmond, San Jose, and San Francisco, and to some extent it affects all the communities located adjacent the Bays. Intensity 9 (R-F) shaking is also forecast for the Santa Rosa-Sebastopol area.

Intensity 8 (R-F) shaking is predicted for those portions of the East San Francisco Bay communities where, in general, the water table is at a depth of more than 10 meters from the surface, in the Diablo and Livermore Valleys, parts of the North Bay and, primarily because of their proximity to the fault, most of the San Francisco and Marin peninsulas.

Most of the remainder of the planning area, generally the more mountainous and less-populated areas east of the Bay, have a predicted intensity of 7 (R-F) or less.

These regional patterns of seismic intensity distribution associated with this scenario event are of sufficient plausibility to form a credible basis for evaluation of general effects upon lifelines that service the greater San Francisco Bay area. The following discussions highlight the anticipated regional consequences on these lifelines.

#### Highways

Map 1-HA displays the regional effects of the scenario earthquake upon the highway system. Damage to highways will have its greatest impact on the San Francisco Peninsula, where vehicular traffic into and out of the City of San Francisco and much of San Mateo County may be impossible for many hours until

one or more corridors become available. Use of the Golden Gate, San Francisco-Oakland Bay, Richmond-San Rafael, and San Mateo bridges will be impossible for an extended period. All peninsula routes west of the San Andreas Fault will be closed. Some major arteries in Santa Clara County will be heavily damaged, but the many available routes will permit rapid restoration of reasonable traffic flow. In the East Bay, routes closest to the Bay margin will be most seriously damaged, notably Route 17 between Richmond and San Leandro. Other major arteries closer to the Oakland Hills will be available, however, subject to occasional detours. Major routes into the damaged areas from the east will be available, including Interstates 80 and 580 with connections to Interstate 680 and Route 24. In the North Bay, the major problems will be along U.S. 101 in the Santa Rosa area and in southern Marin County, where access to and from the area south of San Rafael will be severely limited. Experience has indicated, however, that alternative routes can generally be rapidly developed. While lengthy delays and detours will be common, most of the initial confusion will be under control within a few days.

Planning insights: Emergency planners need to identify major emergency corridors that can be most readily opened immediately following the earthquake. In contrast to some segments of the freeway system that are above or below grade, with many structures subject to damage, alternative emergency routes should be selected which are at grade, wide, not likely to be significantly affected by fallen powerlines or other obstructions, and not flanked by buildings likely to be heavily damaged. Selection of emergency corridors is especially important in the urban areas of San Francisco, San Mateo, and Santa Clara counties, and in Oakland, Berkeley, and Alameda in the East Bay, where significant damage is expected. Wherever possible, alternate corridors should be established so that flexibility is achieved.

The utilities and local government agencies should identify all such installations and facilities that they will need to inspect, repair, operate, or otherwise have access to in this emergency.

Emergency planners need to examine available routes to critical facilities, assess the potential for damage, and identify the most probable access routes. Critical facilities include communication centers, hospitals, airports, heliports, staging areas, fuel storage sites, and other locations essential to emergency response.

Access to the area with supplies and personnel from cities in the Great Valley and southern California will be available. Highway emergency response plans should be coordinated with air, rail, and marine transport scenarios in order to optimize plans for integrated transportation capability. Access to the stricken area and travel within it will be difficult and will be limited to the highest emergency priorities.

Recommended further work: Assessment of highway performance and identification of alternative emergency routes is especially important in all areas where major damage is a reasonable expectation.

#### Airports

Emergency air transport into the stricken region from the outside is vital to response activities during the first 72 hours following the earthquake. Consideration of expectable damage to major airport facilities (see Map 1-HA),

notably the runways and land access routes, leads to the conclusion that the San Francisco International and Metropolitan Oakland International airports, as well as Alameda Naval Air Station and Hamilton Field, will be unavailable for major airborne relief operations (C-141 aircraft and massive logistics). San Jose Municipal, Hayward Municipal, and Buchanan Field will be available with limitations. Thus, delivery of massive emergency aid from outside the area will be hampered by the lack of a close-in major facility. Travis Air Force Base near Fairfield becomes the logical choice for large-scale emergency operations.

Planning insights: Airborne transport will play a vital role in the transport of people and materiel to and from the stricken areas and in search and rescue, damage assessment, and many other emergency response efforts. Pre-selection of one or more air cargo delivery facilities will influence planning for distribution of material by helicopter, highway, rail, and marine transport. Integrating these various delivery systems to accomplish this mission will be challenging. Use of helicopters within the heavily damaged areas is seen as an extremely important function requiring appropriate planning.

Recommended further work: Secondary airports for distribution of supplies and equipment need to be evaluated in terms of the availability of auxiliary electrical power, the integrity of airport buildings, and the vulnerability of surface access ground routes in order to finalize transportation plans. The vulnerability of runways at San Jose Municipal Airport, in particular, needs to be evaluated further, since more data can either confirm or modify the conclusions presented in this report. Facilities suitable for helicopter operations within the stricken area should be selected, particularly in San Francisco, San Mateo, and southern Marin County.

## Railroads

Rail facilities along each of the principal rail corridors leading to the San Francisco Bay Area are subject to major damage and resulting route closure (see Map 1-RM). Therefore, for planning purposes, rail transport to and from the Bay area is assumed to be unavailable for at least the initial 72-hour period following the earthquake. Rail facilities serving the urban areas around the Bay are also highly exposed to damage; while some segments of these lines could be operational, their probable utility would be minimal. Facilities of the Bay Area Rapid Transit System (BART) will be damaged or will require safety inspections to an extent that will render the system totally inoperative during the initial 72-hour post-earthquake period.

Planning insights: Rail facilities within the urban areas surrounding the Bay will be non-operational. Accordingly, if rail transport is essential to recovery efforts, consideration must be given to selection of appropriate rail terminals where material can be off-loaded for truck, airborne, or barge transport. Railheads at Benicia and Vallejo may be most critical for movement of heavy equipment by barge to heavily damaged areas in Marin County and the San Francisco peninsula. Integrated planning needs to be undertaken for air, rail, highway and marine transports.

Recommended further work: Consideration should be given to the possibility of establishing temporary terminals following the earthquake where serviceable tracks come into the Concord and Livermore Valley areas for off-loading of major supplies and equipment. Railheads at Benicia and Vallejo should be examined to determine their adequacy for transport of heavy equipment from rail to barge.

The relative vulnerabilities of the routes that give access to the Bay area via northern Contra Costa County also need to be evaluated. A detailed engineering and geologic examination of these routes may reveal that rail transport to a closer-in staging area near Richmond (that might also permit transfer of materials to barges) is a viable possibility.

#### Marine Facilities

Map 1-RM depicts the earthquake planning scenario for marine facilities in the area. The majority of the docks around the Bay are pile supported and these should not be significantly damaged. Operations at the container terminals, however, which are generally constructed on fill, will be seriously impaired. Disruption of rail facilities, impaired highway access, toppling of cranes, pipeline ruptures, and similar problems will be controlling factors affecting the use of the various port facilities.

The use of barges to transport heavy equipment and supplies to heavily damaged areas will be dependent on the integrity of docks. The major Bayside facilities at San Francisco, Oakland, Richardson Bay, Richmond, and the Carquinez Straits should be accessible for tug and barge operations. South of Hunters Point and San Leandro all facilities would be inaccessible to larger vessels including tug and barge traffic.

Planning insights: The use of tugs and barges to transport heavy equipment and supplies to the San Francisco and Marin peninsulas appears to be a viable emergency-response procedure. Assuming that most of the docks in the

heavily damaged areas will be usable, availability of emergency power and off-loading capabilities will be requisite. Use of barge transport will necessitate coordinated planning for loading of needed material at a dockside facility adjacent to a marshalling depot and/or railhead with corresponding loading capabilities.

Transport of emergency personnel and equipment into these same heavily damaged areas and evacuation of the injured will be a vital function of the numerous Bay ferries. Planning should consider the most feasible terminals (on both ends) in order to complete these missions. Again, coordination with the various ground transport capabilities will be required in order to effect efficient transfers.

The utilization of privately owned vessels to augment this supply and evacuation effort is appropriate. Practical education, planning, and training programs to implement this participation should be initiated.

Recommended further work: The various roles that marine transport can assume in the emergency response efforts and the extent of marine transport resources should be determined. The port facilities in the areas of expected heavy casualties/damage should be assessed, and locations that have suitable land-access and loading capabilities and that are most likely to be available for post-earthquake access to marine transport should be selected. Port facilities outside the heavily damaged areas should be coordinated with ground transport to identify the most efficient means of transporting the injured, materiel, etc.

The capabilities of private vessels and the potential roles of their operators should be determined. Appropriate training programs should be established to ensure the emergency-response effectiveness of this resource.

### Communications

Telephone communications (see Map 1-C) will be adversely affected due to well-known overloading effects resulting from post-earthquake calls within the area and from the outside. This situation will be further complicated by loss of service due to physical damage to equipment from ground shaking and loss of electrical power and subsequent failure of some auxiliary power sources. Moreover, not all of the systems in the region are set up to process emergency calls automatically on previously established priority bases. Thus, overloading of equipment still in service could be very significant.

This post-earthquake communications scenario is primarily an estimate of how much the effectiveness of telecommunications systems will be reduced by the earthquake. "Effectiveness" is defined as the ability of a system to perform to its design limits and provide the intended service following the earthquake. The effectiveness scale is applied to a three-day time frame. Four levels of effectiveness over time were distinguished and used as the basis for zoning the study area (Zones A, B, C, and D). Zone D areas will have the greatest loss of effectiveness over the three-day period, Zone A areas the least.

There is a very good system in San Francisco for identifying important public safety telephone circuits. These dedicated lines should be minimally disrupted. San Francisco is assigned the lowest effectiveness rating (Zone D), however, because (1) the telephone system in the city is expected to have systemic failures not readily compensated by alternative traffic routing and (2) a high percentage of the company employees who will be needed for the recovery effort live outside the city limits and important transportation routes will be impassable. The volume of telephone calls following the earthquake, if it occurred after normal business hours, would not be as heavy and paralyzing to the telephone system in San Francisco, with its high business concentration, as it would be during that time period in more heavily residential areas. But, although the system in San Francisco has line access control, it is more isolated systematically than the Los Angeles metropolitan area, for example, and is very dependent upon a few telecommunications arteries.

In Marin County, telephone system vulnerability was evidenced by the January 1982 storms. The geography and demography is such that alternate routing is limited. Key central offices are located in areas expected to suffer severe shaking and ground failure. Many access routes will be impassable. This area is particularly susceptible to underground cable and surface cable carrier failure. Line load control is available but would not alleviate other systemic problems.

Although the Oakland/East Bay area has a substantial number of telephone facilities located in areas of intense shaking and high probability of ground failure, access to accomplish repairs should not be a major problem. Further, there are several switching options. Systems in this region have line access control and predesignated public safety circuits.

Systems in the San Jose/South Bay area will experience severe shaking intensities and have extensive areas of potential ground failure. Despite this, repair staff should be in reasonable proximity to their offices and have fewer access problems than adjacent areas. The telephone systems will be saturated, but they have designated circuits and line load controls. Because of shaking patterns corresponding with key facility locations, the South Bay area is likely to experience complete localized telephone failures on a block-by-block basis.

Radio systems will generally operate at 40% effectiveness for the first 12 hours after the earthquake, increase to 50% for the second 12 hours, then begin a slow decline to approximately 40% within 36 hours. The long-term implications are that individual systems gradually will become less useful to the overall recovery effort when supplanted by systems relocated from outside the disaster area. It is unlikely that public safety radio systems would become saturated with non-critical communications from mobile units; it is clear, however, that radio traffic densities on redundant (non-emergency-designated) channels would increase, particularly when remote base station and repeater failures would tend to limit the number of redundant channels available. Nonetheless, after 12 hours, at which time the number of operable units will have declined (with exhaustion of emergency power fuel) and recovery efforts will have restored some order, the radio traffic density problem will ease.

Emergency power has been the primary cause of communications failure in past disasters. Poor installation practices and inadequate preventative maintenance of backup power equipment contribute to a high failure rate of radio

systems. The presumed scarcity of propane and gasoline after a major earthquake will strictly limit the viability of surviving communications sites.

The availability of repair parts and the ability to transport them are other factors that should be considered when planning for effective short- and long-range emergency responses. We believe that supplanted communications systems will be needed as local systems suffer earthquake-caused (and normal) equipment malfunctions for which there are no repair parts.

Planning insights: A general communication plan should be developed for use following the earthquake by appropriate agencies and personnel with emergency response roles. This plan should anticipate the needs of the most vital parties. Reliance on emergency telephone communications should be kept at a minimum. A strategy should be developed for communication to the general public which relies upon the capabilities of surviving commercial radio and television stations.

Recommended further work: An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan. A survey of existing critical communications facilities should be undertaken by structural engineers leading to development of improved equipment installation standards. There is need for a technical examination of alternative means of communication, e.g., satellite.

## Water Supply and Waste Disposal

Several of the major aqueducts that deliver imported water to various segments of the planning area will sustain damage causing temporary interruptions in supply (Map 1-W). The numerous major reservoirs in the area provide ample storage to meet demands during the time required for repairs. However, impairments to water transmission lines, local storage reservoirs, and pumping plants, as well as the local distribution systems will affect water availability and pressure. The absence of electrical power for extended periods will in some areas preclude water deliveries where pumping is necessary, even though conveyance facilities may be intact. Many areas will be dependent on tanker trucks to provide their basic needs. For planning purposes, one major dam (Lower Crystal Springs Dam in San Mateo County) is assumed to incur major damage necessitating downstream evacuation procedures.

Sewage collection systems (Map 1-W) will sustain widespread damage, particularly in the low-lying areas nearer the Bay. The many sewage treatment facilities, most of which are located in structurally poor ground adjacent to the Bay, will suffer damage resulting in discharge of raw sewage into the Bay.

Planning insights: The various water agencies need to develop and continue public education programs to acquaint their water users with the prospects of contamination and loss of water supply and how to mitigate these potential problems.

Plans for firefighting need to be coordinated with water agencies and alternative sources of water planned for in critical areas.

Additional interconnections between the major water delivery systems should be considered to provide valuable flexibility in water operations, e.g., connections between the Hetch Hetchy Aqueduct and facilities of the East Bay Municipal Utility District and between the Hetch Hetchy Aqueduct and facilities of the Santa Clara Valley Water District.

Recommended further work: Water agencies need to examine their transmission and distribution systems in detail to identify areas and facilities most likely to be impaired. Ongoing programs should be maintained to progressively upgrade facilities of questionable seismic resistance in areas of high vulnerability.

Capabilities to provide emergency distribution of water using ground transportation need to be evaluated in areas which are identified as having significant possibility of impaired water availability.

Feasibility of providing additional interconnections between various transmission systems should be considered in order to provide alternative supply routes.

There is a need to determine the effects of a prolonged lack of electrical power for pumping water to various portions of the Marin and San Francisco peninsulas.

Fire fighting water requirements should be assessed in critical areas, and estimates should be made of the expected water supply impairment.

## Electrical Power

The occurrence of a great earthquake near this major urban area will have a very significant impact on the many facilities that comprise this complex electrical power network. (See Map 1-E.) Damage to power plants and their ancillary facilities within the planning area and in adjacent areas affected by the earthquake can be expected to result in a reduction in combined generating capacity of up to 50 per cent. The impact of this reduction in output is not expected to be great, however, because power is available from other sources outside the planning area and because of the significant reduction in demand. Immediate concerns will involve repairs necessary to restore power within the damaged areas of greatest need. Major restoration problems will involve repairs necessary to route power through the major substations, repair of damaged and collapsed transmission-line towers, restoration of equipment at local substations, replacement of fallen poles and transformers, etc.

It is a reasonable expectation that virtually all of the planning area will be without power, at least temporarily, during some portion of the first 72-hour period. Algermissen and others (1972) estimated that "It is reasonable for planning purposes to consider 50 per cent of the service connections in the study area to be without power for 24 hours after a magnitude 8.3 shock....in the congested portions of San Francisco and Oakland, the power outage should be considered at 100 percent for 24 hours, and thereafter at 75 percent for an additional 24 hours."

Electrical power facilities on the Marin and San Francisco peninsulas are particularly vulnerable to damage and restoration of power under the best of

conditions could be prolonged. While the resources may be available to expeditiously deal with repairs to the system, the many complicating factors involved in attempting to conduct an extensive repair operation amidst the confusion and destruction that will exist will be a challenge. Realistically, power is unlikely to be restored to many areas for extended periods of time. Planning that involves power dependent systems should take into consideration this possible eventuality.

Planning insights: Society has evolved to where it is highly dependent upon a continuous supply of electrical power to meet a myriad of everyday needs. Consequently, everyone, and particularly those entities responsible for maintenance of lifelines and critical facilities should examine their ability to function in the event of a prolonged absence of electrical power.

At the individual level, the following is very appropriate. Commenting upon the lack of electrical power in Santa Cruz County that resulted from the intense storm during the week of January 4, 1982, Stegner (1982) concluded: "It may be a long time before we need to dig out our old boy scout manuals again, but, while we sit around waiting for the killer earthquake that everybody seems to regard as inevitable, we might take a lesson from the killer storm that nobody expected. The difference between misery and comfort, relatively speaking, may be no more than a can of kerosene and a can of gasoline in the garage, a can of soup in the larder, and a half dozen flashlight batteries in the kitchen drawer. What was the motto? Be prepared?"

IT IS ASSUMED THAT ALL CRITICAL FACILITIES SUCH AS HOSPITALS, FIRE AND POLICE STATIONS, EMERGENCY COMMUNICATIONS AND OPERATION CENTERS, AND WATER

PUMPING STATIONS WILL REQUIRE STANDBY GENERATING EQUIPMENT AND EMERGENCY FUEL SUPPLIES IN SAN FRANCISCO, SAN MATEO, SANTA CLARA, AND MARIN COUNTIES.

Recommended further work: The critical power corridors and facilities should be examined in light of the best geologic data available to assess the vulnerability of various elements in the electrical power network. Capability to respond and accomplish timely repairs to a widespread affected area as described in this scenario should be thoroughly evaluated. Probable interruptions of other lifelines that are discussed in this report should be taken into account in planning an earthquake-emergency response for this utility.

Natural Gas

Damage to natural gas facilities (Map 1-G) will consist primarily of (a) some isolated breaks in the major transmission lines and (b) innumerable breaks in mains and individual service connections within the distribution systems, particularly in the areas of intense shaking and/or structurally poor ground nearer the Bay margins. For planning purposes, it should be considered that these many leaks in the distribution system will affect a major portion of the urban areas in the East Bay, South Bay, and the San Francisco and Marin peninsulas resulting in a loss of service for extended periods. Sporadically distributed fires should be expected at the sites of a small percentage of ruptures both in the transmission lines and in the distribution systems.

Transmission pipelines serving the San Francisco Peninsula are most vulnerable to damage. Damage and repair problems to major transmission lines in

the East Bay should not be significant. No significant damage to transmission facilities in the North Bay is envisioned.

Planning insights: The various major utilities should collaborate in continuing public education programs to explain the probable consequences of a major earthquake on their service capabilities and what actions can be taken to mitigate the effects.

Recommended further work: In areas of structurally poor ground where the potential for major pipeline failure exists, alternative line(s) in stable materials should be considered. The adequacy and location of automatic pressure-activated shut-off valves should be periodically reviewed in the light of new geologic information concerning potential problem areas.

Locations where gas availability would be most severely impacted should be identified. Emergency users of natural gas should be identified. The likelihood of fire due to breaks in local gas mains should also be investigated.

#### Petroleum Fuels

Following the scenario earthquake, operations at the several major refineries in the Bay Area will be curtailed until all facilities are thoroughly inspected and repairs accomplished (see Map 1-P). Pipelines are expected to withstand the shaking fairly well, but ruptures can be expected wherever contrasting ground conditions produce differential movements and wherever ground failure occurs due to liquefaction or seismically-triggered landslides. Large

storage tanks and marine loading facilities located on questionable foundation materials are also subject to damage.

Planning insights: Plans should be developed to ensure distribution of fuel to those locations designated for emergency response operations, including airports. Appropriate facilities, including emergency power and pumping capability, should be available at fuel storage locations for refueling of helicopters and other emergency vehicles. Major damage to the trans-Bay product lines could seriously impact fuel availability on the San Francisco peninsula.

Recommended further work: All petroleum product pipelines serving the metropolitan areas should be examined in detail relative to their exposure to ground failure. The adequacy and locations of automatic shut-off valves should be examined on all product lines and remedial measures undertaken to ensure a functional system. Locations of fuel storage facilities, including those for aviation fuels, should be predetermined and emergency procedures established to ensure that these supplies will be available when needed. An inventory of fuel storage facilities throughout the area would facilitate planning of emergency response efforts that will be dependent upon nearby sources of fuel.

#### ACKNOWLEDGMENTS

This Earthquake Planning Scenario represents input from many sources -- notably, the major public utilities and various smaller utility districts, Federal, State and local government agencies, members of the Advisory Committees of the Governor's Task Force, and the staff of the California Division of Mines and Geology. In addition, many organizations and individuals, requested to comment on various aspects of the work while in progress, provided thoughtful comments on specific items. We particularly want to acknowledge the co-operation and assistance of the major utilities, who were extremely helpful in the compilation of the lifeline inventories and in discussions of the earthquake resistance of various critical facilities. To all who participated in this effort, we express our sincere appreciation.

We are especially indebted to Dr. Karl V. Steinbrugge (Co-Chairman of the Threat Assessment Committee of the Governor's Task Force), who collaborated with us in many areas and who provided guidance and valuable counsel throughout the course of this study.

We are appreciative of Ms. Jan Denton, Director of the Department of Conservation, who has supported this investigation throughout; Dr. Jack F. Evernden, who developed the seismic intensity model and who, with Drs. Roger Borcherdt and Robert D. Nason (all of the U.S. Geological Survey), offered valuable perspectives on the vagaries of forecasting intensity distribution; engineers James A. Gates and Oris H. Degenkolb, who with geologic input from Marvin L. McCauley (all of the California Department of Transportation) provided much of the data for the highways scenario. Recognition must also go to Alex R. Cunningham, Director of the State Office of Emergency Services (OES),

Jack J. Kearns, Deputy Director of OES, and Jane V. Hindmarsh, Special Assistant to the Governor's Emergency Task Force on Earthquake Preparedness; to Dr. William W. Whitson, Chairman of the Governor's Task Force, who provided both inspiration and advice; to Ms. Jeanne Perkins of the Association of Bay Area Governments (ABAG), O.W. Steinhardt and George F. Gaebler of the Pacific Gas and Electric Company, Harry W. Tracy and Jack M. Barron of the City of San Francisco; and to members of various advisory committees of the Governor's Task Force including B. B. Blevins of the California Energy Commission, John E. Brown of John E. Brown and Associates, Inc., Consulting Structural Engineers, Robert L. Cheney of the Pacific Telephone and Telegraph, James G. Cotter and Mason D. Riegel of the California Department of General Services, Donald J. Finlayson of the California Department of Water Resources, John E. Hampton of Marlex Oil and Refining, Inc., Gordon L. Laverty of the East Bay Municipal Utility District, and Michael M. Murphy of Pacific Merchant Shipping Association.

Thanks are also due to Threat Assessment Committee members Rachel Gulliver, Janice Hutton, Roger W. Sherburne, and Dennis S. Miletic.

Within CDMG we wish to accord special thanks to Mary C. Woods, editor of CALIFORNIA GEOLOGY, who has served with James F. Davis, State Geologist, as a member of the Threat Assessment Committee (her help has been indispensable). We are also indebted to Millie E. Anderson, Carole R. Johnson, Yolanda Silva, Darren White, Patty Gouvea, and Cheryl Zeh for typing the manuscript. Merl Smith has supervised drafting efforts and overseen publication. Jeff Tambert, head of the drafting group, did an outstanding job in managing the compilation of the many maps and coordinating the efforts of Ed Foster, Louise Huckabee, Frances Rubish, and Anna Stratton.

## INTRODUCTION

On April 18, 1906, most of northern and central California was shaken by one of the three great (Magnitude 8 +) earthquakes that have struck the State during the past 125 years. Communities throughout the greater San Francisco Bay region were heavily damaged and the resulting fire destroyed much of the City of San Francisco. During the past three-quarters of a century this region, lying alongside the great San Andreas fault, has experienced tremendous growth, evolving into a vast urban complex of several million people.

Sometime during the remaining years of this century or early in the next, the San Francisco area will in all probability again be affected by a great earthquake along the northern segment of the San Andreas fault. An earthquake similar to the 1906 event will have a magnitude of approximately 8 on the Richter scale, and, in addition to its direct impact on a vastly increased population, it will test the many and varied cultural works that have been developed during the interim. Some older facilities will be seriously damaged or destroyed since they were not built to withstand intense shaking and may be situated upon ground that will fail.

This report and accompanying EARTHQUAKE PLANNING SCENARIO maps extend the work begun by Algermissen and others (1972). In addition to predicting the extent of damage likely to occur to lifeline facilities, this scenario endeavors to specify where damage will occur. Because this scenario is based upon the occurrence of a specific earthquake on the San Andreas fault, it is not valid for the assessment of possible damage produced by an earthquake on any other fault or by a different earthquake on the San Andreas fault.

The EARTHQUAKE PLANNING SCENARIO maps included in this report reflect the fact that earthquake damage will not be uniform. Damage will be related to the design of specific structures, the geologic ground conditions upon which they are built, their distance from the fault, and the character of the earthquake generated wave forms to which they are subjected. Many structures have been designed to resist earthquake shaking, while others have not.

The ground surface in areas of competent bedrock is not likely to suffer permanent deformation (ground failure). On the other hand, structures on compressible deposits, particularly where the water table is high, are subjected not only to the effects of relatively low frequency, high amplitude vibrations, but possibly also to disruption caused by differential settlement, lateral displacement, or liquefaction.

In general, earthquake effects diminish with distance from the causative fault. These considerations are reflected in the damage assessments described in this report.

#### How to Use the Earthquake Planning Scenario Maps

For emergency planning purposes, it is important to have an assessment of the effects of the scenario earthquake upon principal lifelines. The present investigation provides a regional characterization of anticipated damage patterns. CDMG's approach in formulating this assessment was, first, to interpret the regional pattern of ground shaking and ground failure and, second, to evaluate the resulting performance of lifeline segments throughout the area.

In this way, CDMG reached conclusions which constitute the regional post-earthquake damage pattern for each of the lifelines. It was not feasible to rigorously determine the effects of the scenario earthquake on each individual bridge, overpass, or other lifeline structure. To accomplish such exhaustive analyses would require subsurface sampling of soil and rock at each site in order to assess potential ground shaking and ground failure. Moreover, an engineering analysis of the manner in which specific structures would respond to the anticipated types of ground shaking would be necessary to draw more definitive conclusions. It is, therefore, improper to use the earthquake scenario conclusions to forecast the effects of the scenario earthquake for any other purpose than emergency planning. For example, decisions on whether or not to replace or retrofit certain lifeline components should definitely be based upon more intensive and rigorous investigations than were practicable for this project.

In general, people in well-designed structures built upon firm bedrock some distance from the fault will be able to aid people in poorly-designed structures built upon soft alluvium near the fault. While no scenario will prove accurate in detail, a general effort such as this provides planners with a regional pattern of the magnitude and types of problems that will confront emergency-response personnel. As more detailed engineering and geologic data become available, these maps will be periodically updated. Other scenarios, could be developed for earthquakes on other faults, or for different earthquakes on the San Andreas fault. Once these scenarios are developed a more complete understanding of the earthquake hazard within the planning area will be possible.

## Limitations Of The Earthquake Planning Scenario Maps

A description of the regional impacts of the scenario earthquake is presented for each lifeline, together with a discussion of the planning insights which are implied by the damage patterns. Where appropriate, further work is recommended. Next, an annotated list of damage assessments for each lifeline precedes the planning scenario maps which portray the geographic location of earthquake effects.

1. The maps in this report illustrate only a regional pattern of damage, specifically, one that it is plausible to expect from a great earthquake (magnitude 8.3) on the northern San Andreas fault. The maps do not present assessments of the damage produced by shaking from earthquakes which may take place on other faults or on other segments of the San Andreas fault.
2. The seismic intensity forecasts upon which the damage distribution is dependent are interpretative. There are various judgments among workers regarding which is the most appropriate model for forecasting intensity.
3. The quality of information upon which the ground-failure forecasts have been made varies from area to area within the study region. Only general geologic information is available concerning ground conditions associated with most lifeline elements. Modeling of ground shaking on a regional basis using this generalized geologic information can produce plausible damage conclusions which are appropriate for emergency planning. Other types of conclusions regarding specific structures, such as the desirability of upgrading seismic resistance, etc., require more detailed geologic information and more extensive engineering analysis than was practical for this study.

SEISMIC INTENSITY DISTRIBUTION  
FOR A M 8.3 EARTHQUAKE ON THE SAN ANDREAS FAULT  
(Map 1-S)

To develop an earthquake planning scenario, it is necessary first to estimate the regional patterns of ground shaking and ground failure. This procedure is aided by assuming that the effects of the scenario earthquake will be interpretable from previous earthquakes about which there is some knowledge. In this instance the scenario earthquake has been assumed to be similar to the great San Francisco earthquake of April 18, 1906. The effects of that earthquake are well documented in the literature, including the classic "Report of the State Earthquake Commission" (Lawson and others, 1908). These observed effects provide a means of confirming the general validity of the regional seismic intensity map developed for assessment of modern lifelines in the San Francisco Bay area.

"Seismic intensity" is the local effect of an earthquake at a particular point of reference (Barosh, 1969, p.6). Unfortunately, forecasting seismic intensity has inherent problems. This is primarily because intensity scaling is based upon generalizations. With a single numerical value, scaling attempts to convey all of the various effects of earthquake shaking upon humans and their cultural paraphernalia. The measurement of seismic intensity, therefore, is unavoidably subjective. Over 44 different intensity scales have appeared during the last century (Barosh, 1969, p.6).

## Regional Seismic Intensity Investigations, in General

Forecasting seismic intensity patterns resulting from a specific earthquake is complicated by other considerations in addition to uncertainties in describing and scaling earthquake effects. Assessing the intensity distribution of an anticipated scenario earthquake requires the investigator to determine approximate ground shaking and ground failure conditions at reference points throughout the area. To scale the intensity of these physical parameters, it is necessary to interpret their consequences upon a variety of types of construction at the reference points.

The degree of ground shaking at a specified location resulting from the scenario earthquake is dependent upon a number of considerations. Among the most influential is the distance from the causative fault. Generally, the amplitude of vibratory motion diminishes away from the source of excitation through the process of attenuation. The vibrations associated with earthquakes are complex. Characterizing their anticipated effects on ground shaking at specific reference points is further complicated by the different geologic materials through which they pass. Well-consolidated bedrock, for example, transmits most frequencies while unconsolidated sand and gravel or water-saturated mud preferentially transmit low frequencies.

Development of seismic intensity maps also requires consideration of the consequences of ground failure. In contrast to vibratory shaking, ground failure is a permanent displacement of earth materials resulting from such

secondary earthquake-induced processes as liquefaction, differential settlement, and slope failure. The potential for ground failure is governed by the presence of susceptible substrate materials such as water-saturated mud or granular materials. Earthquake-caused ground failure has been observed as far as 150 km from the earthquake source.

#### Development of the Seismic Intensity Distribution Map for This Scenario

In preparing a regional intensity map to be employed in the assessment of lifeline damage, CDMG selected the Evernden model (Evernden and others, 1973, 1981; U.S. Geological Survey, 1981). This computer model calculates the ground shaking parameters of particle acceleration on a grid of reference points throughout a region employing equations which include the influence of distance from fault source, attenuation, and the geology of the substrate. The intensities are calculated by using an empirical relationship between acceleration and the Rossi-Forel (R-F) intensity scale. The Rossi-Forel scale was selected by Evernden because he interprets a rather straight-forward mathematical relationship to exist between acceleration and this measure of intensity. The Modified Mercalli (MM) intensity scale, which was developed in 1931 about half a century after the R-F scale, is extensively used today because it provides a classification of earthquake effects related to types of construction. The R-F scale does not distinguish classes of buildings. In order to make the Seismic Intensity Distribution maps developed for this earthquake planning scenario as useful as possible, CDMG will publish a Modified Mercalli scale intensity map of the same area in the near future. Both scales are described and compared in the Appendix of this report.

The U.S. Geological Survey (USGS) has published a series of intensity maps for specific earthquakes, including the M 8.3 event on the northern San Andreas fault that is addressed in this scenario. The geologic substrate information used in the USGS analysis was based upon 1:250,000 scale maps from the CDMG "Geologic Atlas of California." CDMG has modified this intensity map based on more detailed, additional geological information that was not included in the USGS analysis.

The methodology of the Evernden model does not characterize the consequences of ground failure. In order to add this dimension to the CDMG intensity maps, information on local geology and ground water conditions was evaluated in order to identify areas of potential ground failure. These areas are designated on CDMG's Seismic Intensity Distribution maps. Thus, the CDMG intensity map possesses intensity based upon the synthesis of both shaking and ground-failure effects.

#### Areas of Potential Ground Failure in the San Francisco Bay Area

In brief, the areas of high potential for ground failure include all Bay mud deposits (Nichols and Wright, 1971), all areas considered of high liquefaction potential by numerous authors, and most areas in which ground failure was noted in the 1906 earthquake (Youd and Hoose, 1978; Nason, 1980a, 1980b, 1982). These data were checked against detailed work in the literature and modified as indicated below for the nine Bay area counties.

CDMG recognized that landslide deposits are widely but sporadically distributed on upland slopes, and that some of these, particularly in San Mateo, Marin, and Sonoma counties, will be activated by the scenario earthquake. Most of these deposits, however, are too small to be delineated individually at this map scale.

#### Alameda County

The data of Helley, Lajoie, and Burke (1972) was the prime reference. Younger fluvial deposits (Qyfo) north of Newark had historic liquefaction in the 1906 earthquake (Youd and Hoose, 1978). These deposits are considered subject to potential failure along with the underlying deposits (Qb) in the area extending east of Coyote Hills and south to the county line. Some parts of the older Bay mud (Qom) are included because there is historical evidence for failure near Alameda Creek (Youd and Hoose, 1978). Interfluvial basin deposits (unit Qb) are considered unlikely to fail in the region near the Oakland Coliseum. The margins of Alameda Island are included because they consist of loose, well-sorted dune sand (Helley, Lajoie, and Burke, 1972) which is near the water's edge. The central portions of the Island are not included because there was little evidence for liquefaction here in 1906 (Youd and Hoose, 1978). CDMG assumed that this unit (Merritt sand) does not underlie any of the units north of the Bay Bridge or south of Bay Farm Island.

Contra Costa County

The Richmond area is generalized, with units I and II of Bishop and others (1973) considered susceptible to ground failure. To the east of Richmond CDMG used unit III of the Contra Costa County Planning Department (1974).

Marin County

Rice (1973; 1975), Rice and others (1976), and Blake and others (1974) were used to delineate the areas of Bay mud likely to sustain ground failure.

Napa County

Sims and others (1973) was used to delineate the areas of Bay mud.

San Francisco County

CDMG used the data of Jacobs (1974), but excluded some dune sand at higher elevations southwest of Lake Merced.

San Mateo County

In addition to the areas delineated "moderate to locally high" in liquefaction potential by Woolfe and others (1975), the younger basin (Qb) and

beach deposits (Qs) of Lajoie and others (1974) were included. The alluvial fan deposits (Qy and Qyo) in the northeast corner of the county and in east Palo Alto are considered unlikely to fail (Lajoie and others, 1974) and were removed from consideration.

#### Santa Clara County

The historical data of Youd and Hoose (1978) was used to outline the area susceptible to liquefaction along Coyote Creek. In 1906, liquefaction was reported to the east of Guadalupe River, but not to the west. Thus, the Guadalupe River was chosen as the western boundary of the area influenced by liquefiable sands deposited by the Coyote Creek drainage. The potential for liquefaction is considered minimal in the rest of the county (James Berkland and Ben Patterson, geologists, Santa Clara County, oral communication, 1981).

#### Solano County

The data of Sedway/Cooke (1977) was used to define areas of potential ground failure due to liquefaction. A small area surrounding the Gold Hill Undercrossing was included as potentially liquefiable (see note H75 on Map HA).

#### Sonoma County

Blake and others (1974) was used to outline the areas of Bay mud.

## Areas of High Water Table

Areas of high water table (within 10 meters of the surface) were delineated wherever possible, and the predicted intensity was increased by one R-F intensity unit in these areas as suggested by the U.S. Geological Survey (1981). Areas already designated intensity 9 (R-F) were not increased because intensity 10 (R-F) was regarded principally as an indicator of ground failure rather than shaking. As mentioned, the potential for ground failure has to be assessed somewhat independently of the algorithm used to predict shaking intensity.

The areas of high water table were delineated by extrapolating the data of Webster (1973) for the counties of San Mateo, Santa Clara, and Alameda. For Sonoma County, water table data was obtained from the California Department of Water Resources (1981). For the Livermore Valley in Alameda and Contra Costa counties, the estimates of Lunn (1982) were used for the current water table. For the Concord area it was estimated that a high water table would be encountered in those areas less than 40 feet above sea level. For the other counties, data on water table level was unavailable and, consequently, the "areas of high ground water" and areas of "moderate or unknown potential" for ground failure are identical.

Finally, the map was checked against the actual observed intensities for the 1906 earthquake (Nason 1980a, 1980b, 1982; Lawson and others, 1908). Although there was general agreement between predicted and actual intensities for most of the Bay area, the damage to chimneys and unreinforced walls was greater in 1906 than the U.S. Geological Survey (1981) map predicted (7.5 R-F).

for areas in the far East Bay. In the Livermore Valley, for example, it was reported that 50 per cent of the chimneys were thrown down (Lawson and others, 1908, p. 308). Other valleys in that area had similar types of damage, and on this basis CDMG assigned alluvium in the far East Bay a R-F intensity of 8 even where it was unaffected by a high water table.



GENERAL CHARACTER OF THE SEISMIC INTENSITY DISTRIBUTION MAP

The area encompassed in this planning scenario includes most of the more heavily populated areas of the San Francisco Bay region that would be significantly affected by the occurrence of the scenario earthquake, extending from Santa Rosa on the north to San Jose on the south. This scenario earthquake would, of course, cause substantial damage in many communities both north and south of the planning area that are within 50 kilometers or so of the surface rupture. In 1906, damage also occurred in many communities along the western margin of the San Joaquin Valley, although they are located at distances significantly greater than 50 kilometers from the surface rupture. These high intensities have generally been attributed to amplified shaking as a result of the high ground water levels which prevailed at the time of the 1906 event.

As indicated previously, the earthquake selected for this scenario is the repeat occurrence of the San Francisco earthquake of April 18, 1906. This M 8.3 event has its epicenter on the San Andreas fault very near San Francisco. Intense shaking is assumed to occur throughout the planning area for a period of 30-50 seconds. Surface rupture, resulting in a cumulative horizontal displacement across the fault of up to 6 meters, extends from San Juan Bautista to near Cape Mendocino, a distance of some 430 kilometers. No vertical fault slip occurs, and there is no secondary movement along any of the other faults in the region. Many aftershocks, with an occasional event in the M 6-7 range, continue for many weeks.

Predicted intensities resulting from this earthquake are shown on Map 1-S. The areas of predicted intensity 9 (R-F) include most of the low-lying lands surrounding San Francisco and San Pablo Bays. This area of intense shaking encompasses a major portion of the more highly developed urban areas, including most of the Santa Clara Valley and portions of San Francisco, Oakland, and virtually all of the other communities that border these Bays. In addition, portions of this area that are situated on Bay mud are susceptible to ground failures. This additional hazard is present in parts of Oakland, Alameda, Richmond, San Jose, and San Francisco, and to some extent affects all the communities located adjacent to the Bay. Intensity 9 (R-F) shaking is also forecast for the Santa Rosa-Sebastopol area.

Intensity 8 (R-F) shaking is predicted for those portions of the East Bay communities where, in general, the water table is at a depth of more than 10 meters from the surface, in the Diablo and Livermore Valleys, parts of the North Bay and, primarily because of their proximity to the fault, most of the San Francisco and Marin peninsulas.

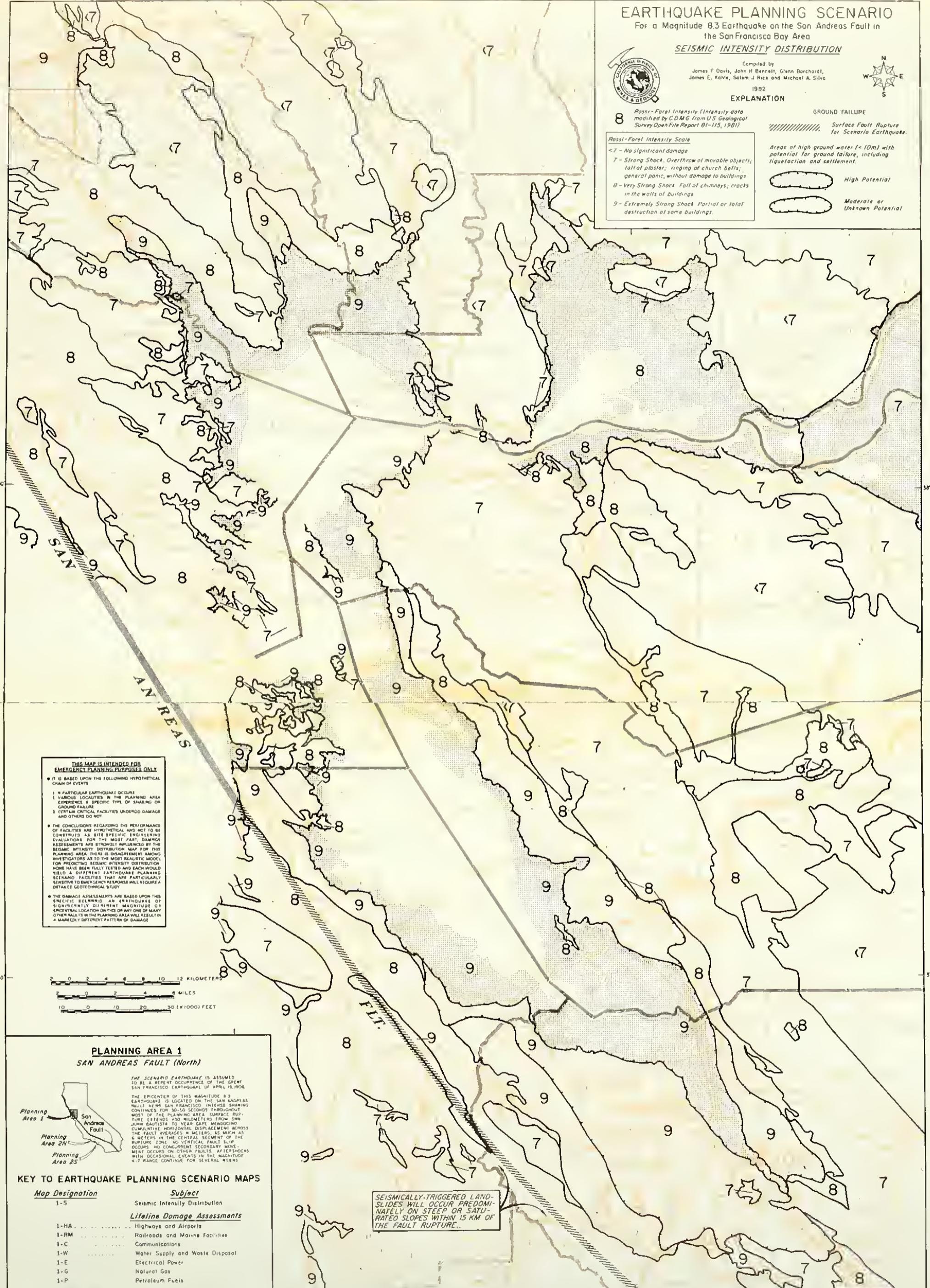
Most of the remainder of the planning area, generally the more mountainous, less-populated areas east of the Bay have a predicted intensity of 7 (R-F) or less.

These regional patterns associated with this scenario event are of sufficient plausibility to form a credible basis for evaluation of general affects upon lifelines that service the greater San Francisco Bay area. The discussions which follow highlight the anticipated regional consequences on these lifelines which are identified in the accompanying maps.

THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







EARTHQUAKE PLANNING SCENARIOS  
FOR LIFELINES  
IN THE SAN FRANCISCO BAY AREA

The capacity for structures to withstand the effects of earthquake shaking, liquefaction, and related ground failure depends upon the soundness of each structure in relation to its geologic environment. Generally, structures within areas of less than intensity 8 (R-F) that are unaffected by ground failure are considered unlikely to sustain significant damage. "Significant damage" is defined here as damage that would render a structure impaired or unusable for 3 to 72 hours after the earthquake--the period most important for emergency response operations.

The following earthquake planning scenarios for lifelines in the greater San Francisco Bay area are based upon an evaluation of the earthquake engineering literature, comments by numerous engineers and other public agency officials, and judgments by the authors. These damage scenarios will hopefully stimulate those concerned with particular lifelines to offer additional insights that will serve to enhance earthquake preparedness efforts in this area. For example, critical corridors in transportation routes and other lifelines became apparent when such routes and lifelines were considered in light of the geologic input. At such critical locations, more extensive evaluations of the geologic hazards and potential damage to lifelines are in order.



EARTHQUAKE PLANNING SCENARIO: HIGHWAYS

Map 1-HA

General Pattern

Damage to the highway network will have its greatest impact on the San Francisco peninsula where vehicular traffic into and out of the City of San Francisco and much of San Mateo County may be impossible for many hours until one or more corridors become available. Use of the Golden Gate, San Francisco-Oakland Bay, Richmond-San Rafael, and San Mateo bridges will be impossible for an extended period. All peninsula routes west of the San Andreas fault will be closed. Some major arteries in Santa Clara County will be heavily damaged, but the many available alternate routes will permit rapid restoration of reasonable traffic flow. In the East Bay, routes closest to the Bay margin will be most seriously damaged, notably Route 17 between Richmond and San Leandro. Other major arteries closer to the Oakland Hills will be available, however, subject to occasional detours. Major routes into the damaged areas from the east will be available, including Interstates 80 and 580 with connections to Interstates 680 and Route 24. In the North Bay the major problems will be along U.S. 101 in the Santa Rosa area and in southern Marin County, where access to and from the area south of San Rafael will be severely limited. Experience has indicated, however, that alternative routes can generally be rapidly developed and, while lengthy delays and detours will be common, most of the initial confusion will be under control within a few days.

Description

Immediately following the earthquake, 25 per cent of the freeways in the Bay Area will be impassable. Damage will be concentrated on the San Francisco peninsula and along the margins of the Bay where freeways are built upon filled areas overlying Bay mud or upon liquefiable alluvial materials that will undergo ground failure. Egress and ingress in the Bay area will be restricted by landslides and cut-and-fill failures along routes through coastal mountains, particularly on the San Francisco peninsula. Although few landslides occurred in the East Bay hills during the 1906 earthquake, some of the many large cuts and fills constructed during recent years will experience some failures.

The disruption produced by the earthquake will create gigantic traffic jams on heavily damaged U.S. 101 from Novato to San Jose and on Route 17 from Richmond to San Jose. Although the four principal Bay bridges will survive the shaking, extensive damage to their approaches will render them temporarily impassable. Both tunnels under the estuary to Alameda will be closed, but at least one of the bridges to the island will remain open. Travel on surface streets in cities will be restricted because of fires, blockades, and rubble.

Within the first 12 hours emergency routes will be cleared along major city streets. For example, major north-south access can probably be opened along Route 82 (El Camino Real) on the San Francisco peninsula and Route 123 (San Pablo Avenue) and Interstate 580 in the East Bay. These routes will be essential to emergency traffic between areas sustaining heavy casualties and hospitals surviving the earthquake. High priority will also be given to

routes to airports and heliports for bringing in rescue personnel and equipment.

Within 24 hours, access from San Francisco to Marin County can be restored when detours become available at the south approach to the Golden Gate bridge. A major source of post earthquake assistance will be the Walnut Creek area, but access to this area is highly dependent upon the integrity of Route 24, and, in particular, the Caldecott Tunnel, which is expected to remain open for emergency traffic although landslides may restrict use of some lanes near the east portals.

Within 36 hours, additional routes should become usable. For example, Route 17 from San Jose to Santa Cruz should be open to singlelane traffic. In Sonoma County, a few damaged bridges on U.S. 101 can be temporarily strengthened to carry limited truck traffic. However, because of severe damage to the Bay bridge approaches, and to freeways built along the margins of the Bay, these major arteries will not be available within the first 72 hours. Accordingly, response planning should not rely upon these major routes for emergency use.

The primary contribution regarding the integrity of major highways was provided by the California Department of Transportation (CDOT, 1981) with the caveat that "this scenario is presented for planning purposes only and may be overly pessimistic in its overall impact." Thus, where numerous bridges, highways, and other facilities are located in areas where failures could occur, CALTRANS has noted the route as closed, even though it is unlikely that the entire route segment would be impassable for the time periods specified.

The alternative is to ignore some possibilities in an arbitrary way. It is important in emergency planning to have contingency plans to deal with all plausible possibilities which may significantly impair ground transportation during the important 72-hour period following this catastrophic event. CDMG worked with the CALTRANS staff to relate geologic conditions and seismic intensity to highway effects.

In certain instances the CALTRANS assessment was modified when additional geologic data and other assessments indicated that this was appropriate. For example, CDMG considered the shaking at the east end of the Caldecott Tunnel to be insufficient to cause landslides large enough to block all lanes and all three tunnels through the East Bay hills.

#### Planning Insights

Emergency planners need to identify major emergency corridors that can be most readily opened immediately following the earthquake. In contrast to some segments of the freeway system which are above or below grade with many structures subject to damage, alternative emergency routes should be selected which are at grade, wide, not likely to be significantly affected by fallen power-lines or other obstructions, and not flanked by larger buildings that are likely to be damaged. Selection of emergency corridors is especially important in the urban areas of San Francisco, San Mateo, and Santa Clara counties and in Oakland, Berkeley, and Alameda in the East Bay, where significant damage is expected. Wherever possible, alternate corridors should be established so that flexibility is achieved.

The utilities and local government agencies should identify all such installations and facilities that they will need to inspect, repair, operate, or otherwise have access to in this emergency.

Emergency planners need to examine available routes to critical facilities, assess the potential for damage, and identify the most probable access routes. Critical facilities include communication centers, hospitals, airports, heliports, staging areas, fuel storage sites, and other locations essential to emergency response.

Access to the area with supplies and personnel from cities in the Great Valley and southern California will be available. Highway emergency-response plans should be coordinated with air, rail, and marine transport scenarios in order to optimize plans for integrated transportation capability. Access to the stricken area and travel within it will be difficult and will be limited to the highest emergency priorities.

#### Recommended Further Work

Assessment of highway performance and identification of alternative emergency routes is especially important in all areas where major damage is a reasonable expectation.

HIGHWAYS

MAP NOTATIONS

(See Map 1-HA.)

<u>NO.</u>	<u>ROUTE</u>	<u>COUNTY</u>
H1	U.S. 101 - Golden Gate Bridge <u>Closed for 24 hours.</u>	San Francisco
	The bridge itself, like the other Bay crossings, will withstand the shaking. Following a post-earthquake inspection, the bridge will be available for pedestrian traffic, providing access is available on both ends. CALTRANS estimates that, for vehicular traffic, it will be closed due to approach failures at the south end, but can be opened to traffic in 24 hours (CDOT, 1981). The Golden Gate Bridge approaches on the north side are vulnerable to major landslides, particularly in the wet season, and virtually complete halt to bridge traffic is possible from landslides (Algermissen and others, 1972, p. 162).	
H2	U.S. 101 - South approach to the Golden Gate Bridge <u>Closed for 24 hours.</u>	San Francisco
	Bridge access will be cut-off by collapse of the Marina Viaduct and soil failures at the Toll Plaza area. Access can be restored via Lincoln Blvd. South within 24 hours (CDOT, 1981).	
H3	Interstate 80 - S.F./Oakland Bay Bridge <u>Closed for over 72 hours.</u>	San Francisco/Alameda
	Blocked at the east end by extensive soil failures and cannot be opened within 72 hours (CDOT, 1981). Following a post-earthquake inspection, the bridge will be usable for pedestrian traffic, providing access is available at both ends. The earth fills of the east approach appear to be subject to extreme slippage and differential settlements. The elevated approach structures on the west end of the Bay Bridge are also subject to failure based on San Fernando experience. Total collapse can be discounted (Algermissen and others, 1972, p. 161).	
H4	Route 1 <u>Open.</u> Open with some delays (CDOT, 1981).	San Francisco

- H5 Interstate 280/U.S. 101 Interchange San Francisco  
Closed for 36 hours.  
Soil failures and bridge collapses; detour can be made available through the area in 36 hours (CDOT, 1981).
- H6 U.S. 101 San Francisco  
Closed for over 72 hours.  
Blocked from Interstate 280 northward and cannot be opened within 72 hours (CDOT, 1981).
- H7 Interstate 280-Potrero Hill slide San Francisco  
Closed for over 72 hours.  
Cannot be opened within 72 hours (CDOT, 1981).
- H8 Downtown Freeway System San Francisco  
Closed for over 72 hours.  
Unusable within 72 hours (CDOT, 1981). The James Lick Skyway is built upon 5-15 feet of very loose fine to medium sand artificial fill over 20 to 70 feet of Bay mud. The fill is dune sand and the 1906 ground failure zone was between 4th and 6th Streets (Youd and Hoose, 1978, p. 43).
- H9 Interstate 80 - Hoffman Avenue Overcrossing Alameda  
Closed for 24 hours.  
Closed due to soil and bridge failures; open to limited traffic in 24 hours (CDOT, 1981).
- H10 Interstate 80 - University Ave. Overcrossing Alameda  
Closed for 24 hours.  
Closed due to soil and bridge failures; open to limited traffic in 24 hours (CDOT, 1981).
- H11 Interstate 80 - Emeryville Alameda  
Closed for up to 36 hours.  
Generally open with delays and obstructions (CDOT, 1981). Closure due to damage described in notes H9 and H10, and other locations by ground failure.
- H12 Webster St. and Posey Tubes Alameda  
Closed for over 72 hours.  
Closed to traffic both ways. No possibility of opening within 72 hours (CDOT, 1981).

- H13 Route 17 Alameda  
Closed for up to 36 hours.  
The hydraulic fills used to construct miles of freeway along the east shore of the Bay in Alameda County may liquefy during heavy shaking, with long sections becoming totally impassable (Algermissen and others, 1972, p. 159). Generally open with delays, obstructions and detours (CDOT, 1981). Many bridges along Route 17 will be heavily damaged and can only carry light traffic (no trucks). A few select bridges can be strengthened to carry limited truck traffic in 36 hours (CDOT, 1981). The elevated section through downtown Oakland is expected to be extensively damaged. Liquefaction and related ground failures will occur between the Bay Bridge approach and the Oakland Coliseum.
- H14 Route 17 - Oakland Airport access Alameda  
Closed for 36 hours.  
Improved airport access at Hegenberger Rd. and Davis Streets could be obtained in 36 hours (CDOT, 1981). Single-lane traffic only at 98th Avenue (CDOT, 1981).
- H15 Route 17 - High St. Interchange Alameda  
Closed for over 72 hours.  
Closed (CDOT, 1981).
- H16 Route 17 - Hegenberger Road Interchange Alameda  
Closed for over 72 hours.  
Improved airport access may be obtained in 36 hours (CDOT, 1981).
- H17 Route 17 - Davis St. Interchange Alameda  
Closed for over 72 hours.  
Improved airport access may be obtained in 36 hours (CDOT, 1981).
- H18 Route 92 - San Mateo Bridge, east approach Alameda  
Closed for over 72 hours.  
Closed due to extensive soil failure at the east approach. No possibility of opening within 72 hours (CDOT, 1981). San Mateo Bridge will be out of operation for an indefinite period due to direct damage to the bridge structures and/or approach problems (Algermissen and others, 1972, p. 162). Following a post-earthquake inspection, the bridge will be usable for pedestrian traffic, providing access is available at both ends.

H19	Route 84 - Dumbarton Bridge - east approach	Alameda
	<u>Closed for up to 12 hours.</u>	
	Open to one-way traffic with delays due to soil failures at east end (CDOT, 1981).	
H20	Route 84 - Niles Canyon Road	Alameda
	<u>Closed for over 72 hours.</u>	
	Closed due to slides and bridge failures. This section cannot be opened in 72 hours (CDOT, 1981).	
H21	Route 84-Sunol to Livermore	Alameda
	<u>Closed for over 72 hours.</u>	
	Closed by slides and collapse of the Arroyo Valley Bridge. No detour possible within 72 hours (CDOT, 1981).	
H22	Interstate 580	Alameda
	<u>Open.</u>	
	Generally open with delays and obstructions (CDOT, 1981).	
H23	Interstate 680	Alameda
	<u>Open.</u>	
	Generally open with delays and obstructions (CDOT, 1981).	
H24	Route 238	Alameda
	<u>Open.</u>	
	Generally open with delays and obstructions (CDOT, 1981).	
H25	Caldecott Tunnel	Contra Costa
	<u>Open within 12 hours.</u>	
	Closed by a partial collapse and slides at east end (CDOT, 1981). We believe this assessment to be overly pessimistic. Shaking is likely to be less than intensity 8 (R-F), suggesting that at least one tunnel and one lane will be open to emergency traffic within the first few hours. "As indicated, a major source of post earthquake assistance will be the Walnut Creek area. Therefore, it is imperative that alternate routes such as Canyon Road be explored for readily available access, other than the Caldecott Tunnel" (McCarty, 1981). "We have no comment on the tunnel. The highway should not be totally closed in Contra Costa County (east tunnel portal to Walnut Creek)" (Dehaesus and Nelson, 1981).	

H26 U.S. 101

San Mateo

Closed for over 72 hours.

Closed for a major portion of the distance from Menlo Park to Candlestick Park, Route 101 cannot be opened within 72 hours (CDOT, 1981). "U.S. 101 between Candlestick Point and San Bruno will be out of service due to land failure" (Algermissen and others, 1972, p. 162). Moderate to high liquefaction potential along most of the length (Woolfe and others, 1975, p. 93). Along U.S. 101 south of Candlestick Point in San Francisco to San Bruno, major land slips or movements are distinctly possible in heavy ground motion, and major stretches of this freeway can be under water or badly damaged due to soil movements (Algermissen and others, 1972, p. 159).

H27 U.S. 101 - San Francisco International Airport Access

San Mateo

Closed for less than 48 hours.

Route 101 access to the San Francisco International Airport is shut off. Access may be re-established in about 48 hours via Route 82 (CDOT, 1981).

H28 Route 1 - Devil's Slide

San Mateo

Closed for over 72 hours.

This notorious slide will close Route 1 even with moderate shaking.

H29 Route 1 - San Andreas Fault Crossing

San Mateo

Closed for over 72 hours.

This route crosses the San Andreas fault near the intersection with Skyline Blvd. (Woolfe and others, 1975, p. 93). Though the 5 meters of right lateral offset could be repaired within 12 hours, landslides along the coast to the south will close the remainder of the route for at least 72 hours. (see note H66).

H30 El Camino Real (Route 82)

Santa Clara/San Mateo

Open.

Open with many major detours and delays to avoid collapsed buildings and bridges (CDOT, 1981). Low liquefaction potential (Woolfe and others, 1975, p. 94). It appears that the brunt of post-earthquake traffic will need to be borne by El Camino Real (Route 82), although here, too, damaged and/or destroyed culverts crossing underneath the roadbed may necessitate local traffic diversions (Woolfe and others, 1975, p. 95).

H31 Great Highway

San Francisco

Closed for at least 72 hours.

Conditions for liquefaction are present (Jacobs, 1974, p. 10a). Parts of the highway will be destroyed by liquefaction of beach sands.

H32	Route 92	San Mateo
<u>Closed for over 72 hours.</u>		
Closed from Half Moon Bay to Route 280 due to slides and faulting and cannot be opened within 72 hours (CDOT, 1981).		
H33	Route 35	San Mateo
<u>Closed for over 72 hours.</u>		
Closed and cannot be opened within 72 hours (CDOT, 1981). Northerly portion crosses San Andreas fault near King Drive (Daly City); landslide potential south of Route 84 (Woolfe and others, 1975, p. 94). Extensive damage due to fault rupture will occur throughout the northern portion of this route.		
H34	Interstate 280	San Mateo
<u>Closed for less than 36 hours.</u>		
Closed at Route 92 by a bridge collapse. A detour can be made around this area in 8 hours (CDOT, 1981). Significant landslide hazard (Woolfe and others, 1975, p. 93). Although this route will be unaffected by fault rupture, its proximity to the fault may subject it to certain near-field effects that are not predictable.		
H35	Interstate 380	San Mateo
<u>Open.</u>		
Closed at U.S. 101; but open from Route 280 to Route 82 (CDOT, 1981). Low liquefaction potential (Woolfe and others, 1981, p. 93). Detours can be made available around the affected interchanges.		
H36	Interstate 380/U.S. 101 Interchange	San Mateo
<u>Closed for over 72 hours.</u>		
It will not be possible to clear the damage within 72 hours (CDOT, 1981).		
H37	Route 37	Napa/Sonoma/Marin
<u>Closed for over 72 hours.</u>		
Closed between Sears Point and Vallejo due to extensive settlement and shift of the roadway. No possibility of opening within 72 hours (CDOT, 1981). The same applies to Route 37 between Sears Point and U.S. 101 where extensive liquefaction will occur between Sears Point and the Petaluma River (S.J. Rice, personal communication, 1981).		

H38 U.S. 101 - north of San Rafael

Marin/Sonoma

Open, with some portions closed for up to 12 hours.

Many overcrossings over U.S. 101 are standing but are heavily damaged and can carry only light traffic (no trucks). A few select bridges can be strengthened to carry limited truck traffic in 36 hours (CDOT, 1981). The heaviest damage will be concentrated in Petaluma and between Cotati and Santa Rosa. Liquefaction damage will close the interchanges with Routes 17 and 37 for up to 12 hours.

H39 Route 84

San Mateo

Closed for over 72 hours.

Closed from San Gregorio to Woodside due to extensive slides and cannot be opened within 72 hours (CDOT, 1981). High landslide potential (Woolfe and others, 1975, p. 94). The mountainous areas of San Mateo County had numerous landslides in the 1906 event, which followed a March of record rainfall (Youd and Hoose, 1978).

H40 Route 1

Marin

Closed for over 72 hours.

Closed at numerous locations due to slides, slipouts, and bridge failures. No possibility of opening within 72 hours (CDOT, 1981).

H41 Route 17 - Richmond/San Rafael Bridge approach

Marin

Closed to vehicles for at least 72 hours.

Heavily damaged and settled. No possibility of opening within 72 hours (CDOT, 1981).

H42 U.S. 101

Marin

Closed for 12 hours.

South of San Rafael U.S. 101 is closed by pavement breaks and settlements and by one bridge collapsed over the freeway. Repairs and detour can be made in 12 hours. Many bridges over and on U.S. 101 are damaged and capable of carrying light traffic only (no trucks). A few select bridges can be strengthened to carry limited truck traffic in 36 hours (CDOT, 1981).

H43 Geary Blvd.

San Francisco

Open.

A major E-W route connecting Ocean Beach with downtown. The route has no liquefaction problems and a possible landslide (Jacobs, 1974, p. 10a) can be avoided by a detour.

- H44 Route 17 - Richmond/San Rafael Bridge approach Contra Costa  
Closed for at least 72 hours.  
Heavily damaged and settled. No possibility of opening within 72 hours (CDOT, 1981).
- H45 Interstate 680 - Carquinez Bridge approach Contra Costa  
Closed for less than 12 hours.  
Damaged but opened within 8 hours after approach work and inspection (CDOT, 1981).
- H46 Interstate 680 - Benicia/Martinez Bridge approach Contra Costa  
Closed for less than 12 hours.  
Damaged but opened within 8 hours after approach work and inspection (CDOT, 1981).
- H47 Interstate 680 - south of Benicia/Martinez Bridge Contra Costa  
Closed for less than 12 hours.  
Closed due to extensive soil failure. This route may be opened to fourwheel-drive vehicles in two hours and opened to limited traffic in 12 hours (CDOT, 1981). This area is filled marsh (Nichols and Wright, 1971).
- H48 Route 4 Contra Costa  
Closed for less than 12 hours.  
Closed between Interstates 80 and 680 due to extensive soil failure and collapse of Alhambra Avenue UC (undercrossing). No possibility of opening within 72 hours (CDOT, 1981). "We doubt that Route 4 will be totally closed by landslides; one lane should remain open or can be readily opened (less than 3 hours). Even if Alhambra Avenue UC collapses, alternate ramps in the interchange should be available" (Dehaesus and Nelson, 1981).
- H49 Interstate 680 - Benicia Viaduct Solano  
Open.  
The footings are in bay marsh (Nichols and Wright, 1971), but apparently founded in nonliquefiable material.
- H50 Interstate 80 - Willow Ave. UC Contra Costa  
Closed for less than 12 hours.  
Damaged and closed to all traffic for inspection. Detour available through Pinole. May be open to single-lane traffic in 3 hours (CDOT, 1981).

H51 Interstate 80 - Appian Way Hilltop Slide Contra Costa  
Open.

This landslide will restrict traffic on Interstate 80 to one lane each way. May be opened up to two lanes each way in 48 hours (CDOT, 1981).

H52 Interstate 680 Contra Costa  
Open.

Many overcrossings will be standing but these will be heavily damaged and can carry only light traffic (no trucks). A few select bridges can be strengthened to carry limited truck traffic in 36 hours (CDOT, 1981). This may be an overly pessimistic assessment since predicted shaking in this area is only intensity 8 (R-F). "We do not believe soil failures will close I-680" (Dehaesus and Nelson, 1981).

"From the Caldecott tunnel an alternate route to I-680 northbound is available over Pleasant Hill Road-Taylor Blvd. Expressway. The only serious restriction may be Pleasant Hill Road OC (Taylor Blvd.). From the foundation and approach fill standpoint the bridge will remain serviceable or can be readily restored to service, and in any case the southbound 2 lanes would not be affected except by minor rockfalls. The route should be open from Pleasant Hill Road interchange with Highway 24 to Willow Pass Road OC (overcrossing) and Taylor Blvd. junction on I-680 in Concord" (Dehaesus and Nelson, 1981).

H53 Route 123 – San Pablo Ave., south of Cutting Blvd. Contra Costa/Alameda  
Open.

Primary N-S emergency route in Berkeley-Albany area. Areas of liquefaction (Bishop and others, 1973) may require detours further east. Severe congestion is expected to affect San Pablo Avenue (Dehaesus and Nelson, 1981).

H54 San Pablo Dam Road Contra Costa  
Closed for less than 12 hours.

Although there are numerous landslides between San Pablo Dam and points further east (Bishop and others, 1973), the shaking intensity will not produce more than small cut and fill failures.

- H55 Route 17 - Hoffman Ave. off ramp to Richmond-San Rafael Bridge Contra Costa  
Closed for more than 72 hours.  
High liquefaction potential for all but segment through San Pablo Hills (Bishop and others, 1973).
- H56 Route 123 - San Pablo Ave., north of Cutting Blvd. Contra Costa  
Open.  
Primary N-S emergency route through Richmond. There is potential for liquefaction between Cutting Blvd. and Interstate 80-San Pablo Blvd. interchange and again at San Pablo Creek (Bishop and others, 1973).
- H57 Route 17 Santa Clara  
Closed for more than 72 hours from Fremont to San Jose and for less than 36 hours from San Jose to Santa Cruz.  
According to CDOT (1981), this route will be closed from Milpitas to Santa Cruz due to extensive soil and bridge failures. May be opened to single-lane limited traffic in 36 hours, but Louis (1981) states: "While we have no knowledge of the performance of the structures, in general the foundation soils and the cut slopes are expected to experience only local and relatively minor distress."
- H58 Route 9 Santa Clara  
Closed for at least 72 hours.  
Closed and cannot possibly be opened within 72 hours (CDOT, 1981).
- H59 Route 35 Santa Clara  
Closed for at least 72 hours.  
Closed and cannot possibly be opened within 72 hours (CDOT, 1981).
- H60 Route 237 - Milpitas to Mountain View Santa Clara  
Closed for at least 72 hours.  
Closed due to massive liquefaction failures. This route cannot be opened within 72 hours (CDOT, 1981). Substandard overcrossings at the East Mountain View overhead and Mountain View railroad overhead (Eggleson, 1980). Possible liquefaction may occur along most of the route (County of Santa Clara Planning Department, 1976, p. 53). Louis (1981) states that site-specific studies suggest that liquefaction is most likely to be a minor problem and differential settlement is likely to be more troublesome. Damage to Route 237 will be confined to the section east of the Guadalupe River.

- H61 El Camino Real (Route 82) Santa Clara  
Open.  
Open with many major detours and delays to avoid collapsed buildings and bridges (CDOT, 1981). Substandard overcrossings at Blossom Hill Road and Hillsdale Avenue-Capital Expressway (Eggleson, 1980).
- H62 Interstate 280 - San Jose to Los Altos Santa Clara  
Open.  
Open with some obstructions and delays (CDOT, 1981). Possible liquefaction hazard near Cupertino (County of Santa Clara Planning Department, 1976, p. 53). Site-specific studies suggest very shallow groundwater and liquefiable materials may result in local failures of fills. Some cut slopes may also experience local failures (Louis, 1981).
- H63 U.S. 101 - Gilroy to San Jose Santa Clara  
Open.  
Open (CDOT, 1981). Same comments as note H62; however, this route does not have the number of embankments that are found on Interstate 280 (Louis, 1981).
- H64 U.S. 101 - San Jose to Menlo Park Santa Clara  
Closed for over 72 hours.  
Closed due to bridge and highway failures. This portion cannot be opened within 72 hours (CDOT, 1981). Possible liquefaction hazard present along most of length (County of Santa Clara Planning Department, 1976). Site-specific studies do not indicate problems in the foundation soils, and differential settlement is likely to be the most significant problem (Louis, 1981). See list of 29 substandard overcrossings (between San Jose and South San Francisco) in Eggleson (1980).
- H65 Interstate 680 (south) Santa Clara  
Open to U.S. 101 south, but closed between U.S. 101 and Route 82 for less than 12 hours.  
Possible liquefaction along this route (County of Santa Clara Planning Department, 1976, p. 53). Route contains few, if any, slopes greater than 30% (p. 25). "Site specific studies indicate no soils or foundation problems along this alignment" (Louis, 1981).
- H66 Route 1 - Daly City to Santa Cruz San Mateo  
Closed for over 72 hours.  
Closed from Daly City to Santa Cruz due to slides and slipouts. No possibility of opening within 72 hours (CDOT, 1981).

- H67 Route 13 - Route 24 to Interstate 580 Alameda  
Open.  
Numerous alternate routes are available. This route parallels the Hayward fault. However, there was no sympathetic movement along the Hayward Fault during the 1906 event (Lawson and others, 1908) and none is assumed in this scenario.
- H68 Route 24 - Caldecott Tunnel to Route 17 Alameda  
Open.  
Numerous alternate routes are available.
- H69 Claremont Ave. - Fish Ranch Road Alameda  
Open.  
Alternate route to the Caldecott Tunnel (Route 24).
- H70 Bridge Access to the City of Alameda Alameda  
One, or more, open.  
CDOT did not give an assessment of the Route 62 bridge crossing of San Leandro Channel to the City of Alameda. Also, no assessment is made of the bascule bridges maintained by Alameda County. Without these assessments the potential for isolation of the City of Alameda is unknown (Lanferman and Danehy, 1981). Of these four bridges, we consider it unlikely that all will be closed.
- H71 Route 4 - Concord to Antioch Contra Costa  
Open to Route 160.
- H72 Route 160 Sacramento  
Open from Route 4 to Antioch Bridge. Closed from Antioch Bridge to Brannan Island.  
Due consideration should be given to the levees in the Delta complex. Some of these facilities carry vital transportation routes and are certainly subject to liquefaction (Stiver, 1981).
- H73 Route 29 Napa  
Open.

H74 Route 12

Sonoma/Napa

Open.

H75 Interstate 680 - Gold Hill Undercrossing

Solano

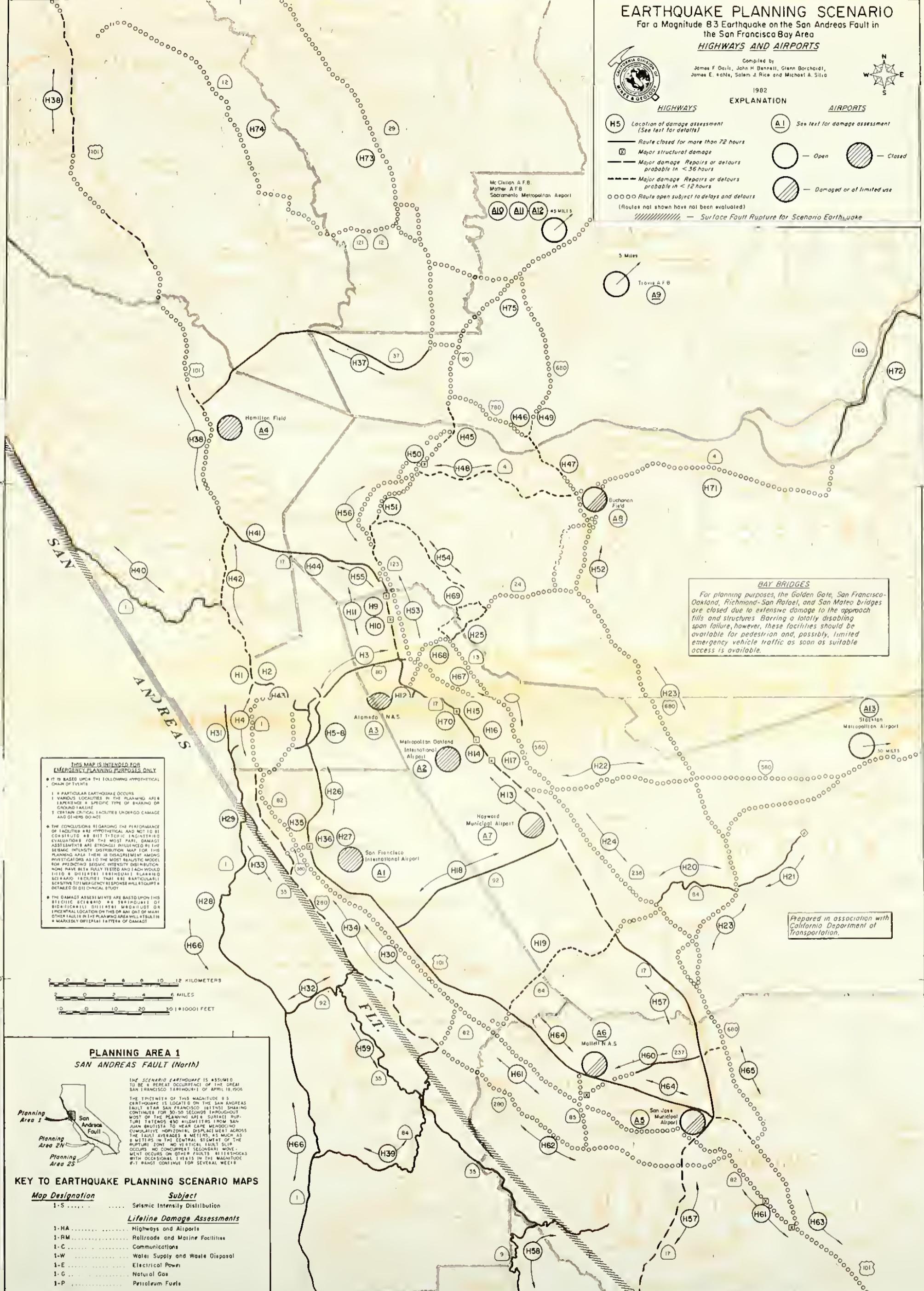
Open.

There is evidence for lateral spreading northwest of the undercrossing, and this, combined with data showing that (a) the water table was at 7 feet in 1963 and (b) a loose brown silty gravelly sand layer lies between depths of 21 and 24 feet at the undercrossing may indicate a liquefaction hazard in the area. The bridge, however, is built on steel pipe piles founded in nonliquefiable material (A. F. Goldschmidt, Engineering Geologist, CALTRANS, oral communication 1982).

THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







## EARTHQUAKE PLANNING SCENARIO: AIRPORTS

### Map 1-HA

#### General Pattern

Emergency air transport into the stricken region from the outside is vital to response activities during the first 72 hours following the earthquake. Because of expected damage to major airport facilities, notably the runways and land access routes, San Francisco International and Metropolitan Oakland International airports, as well as Alameda Naval Air Station and Hamilton Field, will be unavailable for major airborne relief operations (C-141 aircraft and massive logistics). San Jose Municipal, Hayward Municipal, and Buchanan Field will be available with limitations. Thus, delivery of massive emergency aid from outside the area will be hampered by the lack of a close-in major facility. Travis Air Force Base near Fairfield becomes the logical choice for this operation.

#### Description

Four of the eight major airports most accessible to the stricken areas are built upon fill overlying soft Bay mud. A fifth is in an area of high water table and is subject to intense shaking. Intense shaking and subsequent ground failure along the margins of San Francisco Bay will make runways located in these areas unusable.

According to Algermissen and others (1972, p. 169), "San Francisco International Airport, Oakland International Airport, and Alameda Naval Airbase Airport are in regions of structurally poor ground (Bay mud areas), and Hamilton Air Force Base Airport soils are open to some question from a structural standpoint. In the event of high intensities at these four airports, the runways will be considered to be badly broken for planning purposes even though experience does not fully confirm this. The runways on the other airports are expected to remain in operation, or become operational again in hours."

Only San Jose Municipal, Hayward Municipal, and Buchanan Field (near Concord) have a reasonable chance of surviving the earthquake without serious disruption of runway integrity. Buchanan Field will be subjected to less shaking than the others but, similar to Hayward Municipal Airport, it can support only the smaller C-130 aircraft used in emergency operations. (C-130's require at least 5,000 ft. of runway and pavement strength to withstand 130,000 lb. wheel weights (dual tandem)). Only San Jose Municipal Airport remains as a close-in airport that is large enough for C-141 aircraft. (C-141's require at least 5,000 feet of runway and pavement strength to withstand 250,000 lb. wheel weights (dual)). Detailed engineering-geologic studies of these three airports, particularly San Jose Municipal Airport, may suggest warranted improvements in emergency handling facilities. Outlying airports such as Travis Air Force Base, and the Sacramento and Stockton Airports, will be available, but the response effort will be delayed because of the necessity to transport cargo a greater distance to the stricken area.

Airborne transport will play a vital role in the transport of people and materiel to and from the stricken areas and in search and rescue, damage assessment, and many other emergency response efforts. Pre-selection of one or more air cargo delivery facilities will influence planning for distribution of material by helicopter, highway, rail, and marine transport. Integrating these various delivery systems to accomplish this mission will be challenging. Use of helicopters within the heavily damaged areas is seen as an extremely important function requiring appropriate planning.

Recommended Further Work

Secondary airports for distribution of supplies and equipment need to be evaluated in terms of auxiliary electrical power supply, integrity of airport buildings, and vulnerability of access routes in order to finalize transportation plans. The vulnerability of runways at San Jose Municipal Airport, in particular, needs to be evaluated further since more data can either confirm or modify the conclusions presented in this report. A plan of action, with established equipment and supplies and listed tangible resources for a sustained effort, should be prepared. Facilities suitable for helicopter operations within the stricken area should be selected, particularly in San Francisco, San Mateo, and southern Marin County. A statewide system of priority identification (see Walford and Kermit, 1981) should be established for personnel who are essential to the emergency-response efforts at airports such

as Buchanan Field and San Jose Municipal Airport that are likely to have runway integrity following the earthquake. Such a system should assure that these personnel can secure official assistance in getting to their areas of responsibility when access is restricted due to traffic jams or other blockages. Developing such a system is of the highest priority because the expertise of these personnel is crucial to the planned emergency response.

AIRPORTS

MAP NOTATIONS

(See Map 1-HA.)

<u>NO.</u>	<u>AIRPORT</u>	<u>COUNTY</u>
A1	San Francisco International Airport (SFO) <u>Closed for over 72 hours.</u>	San Mateo
	SFO is built entirely on fill (Nichols and Wright, 1971), and the water table is within 5 feet of the surface (Webster, 1973). The SFO area was filled by using construction procedures designed to displace the Bay mud (R.D. Borcherdt, personal communication, 1981), but its effectiveness in preventing runway damage during large earthquakes remains to be established. According to Algermissen and others (1972, p. 169), SFO will be closed for several weeks, and practical land access will not exist to San Francisco Airport due to freeway and highway damage which will effectively isolate the airport and nearby facilities.	
A2	Metropolitan Oakland International Airport (OAK) <u>Closed for over 72 hours.</u>	Alameda
	OAK is built entirely on Bay fill (Nichols and Wright, 1971), and the water table is within 5 feet of the surface (Webster, 1973). It is not likely to be useable for large transport cargo aircraft. According to Algermissen and others (1972, p. 169), OAK will be closed for no longer than one week.	

A3 Alameda Naval Air Station (NAS)

Alameda

Closed for over 72 hours.

Alameda NAS is built entirely on Bay fill (Nichols and Wright, 1971), and the water table is within 5 feet of the surface (Webster, 1973). It is unlikely to be useable for large transport cargo aircraft. According to Algermissen and others (1972, p. 169), Alameda NAS will be closed for no longer than one week.

A4 Hamilton Field

Marin

Closed for over 72 hours.

Hamilton Field is built entirely on Bay fill (Nichols and Wright, 1971), and the runway is only about 2 feet below sea level. According to Rice (1973), the airport lies in an area of major damage, which in this setting is likely to result from secondary effects of the earthquake vibrations, especially from differential settlement and disruption of the fill caused by accelerated compaction or lateral flow of the mud beneath the fill. See also Rice (1975) and Rice, Smith, and Strand (1976). According to Algermissen and others (1972, p. 169), Hamilton Field will be closed for no longer than one week.

A5 San Jose Municipal Airport

Santa Clara

Open for limited use.

To estimate the conditions of the runways following the scenario earthquake with any confidence would require more analysis. In the meantime, for planning purposes the facility should not be depended upon for access to the region from the outside. Webster (1973) states that the water table at this location is mostly at depths greater than 20 feet, but Laird and others (1979, p. 42) indicate the water table is within 10 feet of the surface. According to Troup (1981) "water table depths vary throughout the Airport. A soils investigation by Woodward-Clyde Consultants on May 1, 1981, located water table depths in the 15- to 16-foot range with one test hole showing a depth of only 13 feet." Perkins and others (1981) state that this is not an area of high liquefaction potential, but according to the County of Santa Clara Planning Department (1976, p. 53) it is in an area of possible liquefaction. Within the first 4-12 feet, only one of 150 borings had liquefiable unconsolidated material at or near the runway (Troup, 1971). According to Troup (1981), test borings do not greatly indicate liquefaction potential. However, the existence of compressible materials underlying the runways and the varying structural sections due to stage construction of the runways support a potential problem of differential settlement. Therefore, it is possible that the runways would not be open or available for emergency purposes. The Airport Terminal building was designed to support a second story which was never built. However, an analysis based on new earthquake standards has not taken place to determine the adequacy of the structure (Troup, 1981). There is a generator for indoor lighting, etc., but none for fuel pumps (Verne B. Troup, Deputy Director Airport Planning and Development, oral communication, 1981). Runway length is 8,900 feet,

which is sufficient for large-scale rescue operations. According to Algermissen and others (1972, p. 169), the runways at San Jose are expected to remain in operation, or become operational again in hours.

A6 Moffett Field Naval Air Station

Santa Clara

Open for limited use.

The water table is within 5 to 10 feet of the surface (Webster, 1973). Only the northern tip of the runway is built upon Bay fill (Nichols and Wright, 1971), but liquefaction may be likely at the site (Perkins and others, 1981). The longest runway is 9,000 ft. and maximum allowable wheel weight is 257,000 lb. gross load weight (dual tandem wheel load capacity) which is sufficient for C-141 aircraft. It is asphalt/concrete. The nearness of this airport to the fault, the airport's association with Bay mud, and its location in an area of high water table all indicate that it might be disrupted considerably during the earthquake. For planning purposes, this facility should not be considered a reliable means of air-transport access unless suitability is established by further work. However, according to Algermissen and others (1972, p. 169), the runway is "expected to remain in operation, or become operational again in hours."

A7 Hayward Municipal Airport

Alameda

Open for limited use (C-130 aircraft or smaller).

The water table here is at depths of 5 to 20 feet (Webster, 1973), the airport is not built on Bay mud (Nichols and Wright, 1971), and the liquefaction potential is not high (Perkins and others, 1981). The length is sufficient (5,156 ft), and the "dual tandem wheel load capacity is 300,000 lbs. gross load weight, more than sufficient for the C-130" (Castenada, 1981), but the dual wheel capacity (190,000 lbs.) is insufficient for C-141 aircraft. Castenada (1981) anticipates "that large fire suppression apparatus would need to be moved from Oakland Airport, for example, to accomodate the emergency activities at Hayward involving large aircraft." "Your office inquired about liquefaction at the Hayward Airport and your assessment appears correct. However, [we] have since become aware that the enclosed channel of Sulphur Creek extends under the main runways (roughly east-west across the north-westerly end of the runways) and any failure of that structure may cause isolation of the complete southwest-northeast runway" (Lanferman and Danehy, 1981). Hayward Municipal Airport should not be relied upon to provide air-transportation access into the area unless suitability is established by further work. According to Algermissen and others (1972, p. 169), the runway is expected to remain in operation, or become operational again in hours.

A8 Buchanan Field

Contra Costa

Open for limited use (C-130 aircraft or smaller).

The facility is not built upon Bay fill (Nichols and Wright, 1971). Liquefaction potential is not high (Perkins and others, 1981). Buchanan

Field is 23 ft. above sea level and the water table is at 6 ft. There is an emergency generator for the tower, but none for night operation of runway lights or for fuel pumps (Vance Roskelley, Airport Operations Supervisor, oral communication, 1981). Buchanan Field's longest runway is 5,000 ft. with a maximum weight allowed of 90,000 lb. (dual) and 140,000 lb. (dual tandem). It can handle DC-9 and C-130 aircraft, but not the C-141 aircraft necessary for large-scale emergency operations. It is estimated that the field could comfortably handle six (6) C-131 size aircraft at a time, parking them on the inactive major runway and possibly as many as twelve (12) in a cramped situation, or the same number of large turbine helicopters with similar parking arrangements. Air Navigational Aides - The F.A.A. dictates that, in an emergency situation, Field Sector Maintenance Personnel are first to make certain the microwave link repeater stations (off the airport) are functioning properly before attending to communications at Buchanan. The Tower does have a backup communications system ready should the active system fail. Aircraft Fuel - No need to fuel the large aircraft is anticipated because they could fuel at the airports on the other end of their flight. Helicopters have a shorter range and would need fueling services here. About 3,000 to 12,000 gallons of jet fuel should be on hand to fuel helicopters, although the Martinez Shell Oil Refinery (7 miles distance) usually stores some jet fuel and, if need be, the helicopters could refuel at the refinery. Airport Lighting - The Control Tower has an auxiliary generator for communications only (Walford and Kermit, 1981). An auxiliary 200 kw power generator is needed for runway and taxiway lighting (44 kw) and to power the Terminal Building (156 kw), to enable its use as a coordination and relief center. Also needed are smaller portable generators with lighting to illuminate the aircraft loading and unloading areas. Roadway Access to Field - "At the beginning of a 3 or 4 day weekend, the vehicular traffic on Interstate 680 is bumper-to-bumper, stop and go. For that reason, I personally do not believe that ground traffic to and from this airport will be possible for several hours. (Panic - people concerned for relatives, etc.) The main access to the Airport is John Glenn Drive off of Concord Avenue on the south side of the Airport (normally moderately heavy traffic except at commute times when it is stop and go). A new access soon to be available will be from Highway 4 to Solano Way to Highway 4 frontage road to Marsh Drive onto the west side of the Airport. There is also presently an off ramp southbound from Interstate 680 at Pacheco to Contra Costa Boulevard to Center Street onto the west side of the Airport..." (Walford and Kermit, 1981). According to Algermissen and others (1972, p. 169), the runways are expected to remain in operation, or become operational again in hours.

A9 Travis Air Force Base

Solano

Open.

The facility is not built upon material with high liquefaction potential (Perkins and others, 1981). The area is not underlain by Bay mud and it is not subject to liquefaction (Sedway/Cook, 1977, p. 4a). The chances for Travis AFB surviving the earthquake in a fully operational condition are excellent. It should be seriously considered as the principal staging area for the earliest assistance from Federal and State government.

A10	McClellan AFB	Sacramento
	<u>Open.</u>	
	Outside the area of intense shaking.	
A11	Mather AFB	Sacramento
	<u>Open.</u>	
	Outside the area of intense shaking.	
A12	Sacramento Metropolitan Airport	Sacramento
	<u>Open.</u>	
	Outside the area of intense shaking.	
A13	Stockton Airport	San Joaquin
	<u>Open.</u>	
	Outside the area of intense shaking.	

EARTHQUAKE PLANNING SCENARIO: RAILROADS

Map 1-RM

General Pattern

Rail facilities along each of the principal rail corridors leading to the San Francisco Bay area are subject to major damage and resulting route closure. Therefore, for planning purposes, rail transport to and from the Bay area is assumed to be unavailable for at least the initial 72-hour post-earthquake period. Rail facilities serving the urban areas around the Bay are also highly exposed to damage, and while some segments of these lines could be operational, their probable utility would be minimal. Facilities of the Bay Area Rapid Transit System (BART) will be damaged or will require inspection for damage to an extent that will render the system totally inoperative during the initial 72-hour post-earthquake period.

Description

Because track alignments must be precise and the track clear of debris, it is expected that those routes experiencing ground failure would not be operable within the first 72 hours after the earthquake. In San Francisco the Southern Pacific Commuter Line and the Municipal Railway will be out of operation. In Oakland, the AMTRAK Station will be closed. All intra-urban travel by rail will be halted.

For emergency response, railroad access to the San Francisco Bay area from outside the affected area is of paramount concern. Emergency planning

for rail transport of relief equipment and supplies will involve location of suitable terminals just outside the areas where the major rail lines are interrupted.

From the south, rail access will be cut where it was in the 1906 earthquake--at the Pajaro River bridge east of Watsonville. Consequently, rail traffic from the Los Angeles region would have to be routed through the San Joaquin Valley. From the San Joaquin Valley, the two major rail corridors will be closed in Niles Canyon east of Fremont and near Port Chicago in northern Contra Costa County. The remaining major rail corridor from the north and east will be temporarily closed by ground failure in the crossing of Suisun Marsh southwest of Fairfield. The assumed rapid repair of this main line would allow for transport of heavy equipment and supplies by rail to suitable docking facilities at Benicia where barges could be loaded for continued transport to the heavily damaged area around the Bay. Marine facilities at Vallejo could also be accessible to the railroad via the line (which should remain open) from Fairfield through Jameson Canyon to Vallejo.

The rail closure near Port Chicago suggests that the Naval Weapons Station might be considered as a convenient terminal for some rail transported material. Similarly, the closure in Niles Canyon suggests the same possible use for Camp Parks.

The most widespread damage to railroads will occur at those locations of structurally poor ground where the roadbed will be seriously disrupted by ground movement. These types of failures can generally be rapidly repaired, however, given the equipment and personnel that the railroads maintain for their normal maintenance operations.

According to Algermissen and others (1973), railway bridges generally do not suffer serious damage except in areas subject to ground failure or surface fault rupture. Bridge damage, when it does occur, however, generally involves a lengthy repair time. Significant settlement of approach fills require repair before bridge structures can be used. Railroad tunnels experience severe damage in areas affected by permanent ground movements due to landslides or surface fault rupture, but rarely suffer internal damage from ground shaking.

Rail facilities are also highly vulnerable to closure by collapse or major damage to the many freeway overcrossings and other grade separation structures that have been constructed during the past 30 years.

#### BART

The Bay Area Rapid Transit (BART) system is designed to withstand a 1906-type earthquake and it has "other built-in features that are helpful in reducing damage from an earthquake, such as a very heavy car base, two derail bars per car mounted diagonally to instantly cause full braking of the train...as soon as a train wheel leaves the rail" (LNG Task Force, 1980, p. III-19). The scenario event will immediately trip the BART strong motion detector in Daly City. Unfortunately, this will not, in itself, slow the trains. Instead, it will send a signal to central control which will then communicate with train operators to slow the trains (Snyder, 1981). If electrical power is available, the trains will then proceed slowly to the next station where they will await determination of damage. The magnitude of its power requirements make the development of an emergency generating system for

BART operation impractical, although there is sufficient emergency generating capacity to maintain computer control for a few hours.

People stranded in subways, tunnels, or in the TransBay tube can leave on foot. The TransBay tube can be cleared of trains with the use of gasoline or diesel-powered "Hi Rail" vehicles, thus opening a route between San Francisco and the East Bay. While the BART system has been designed to withstand a M 8.3 earthquake on the San Andreas fault without incurring irreparable structural damage, it would be unrealistic to expect no damage. After passenger evacuation, it would undoubtedly be shut down for an indefinite period while damage was assessed and repairs were made. Portions of the system could presumably be available for use by the authorities, either with PG&E power or using Hi Rail equipment. However, it would be of very limited use compared to a railroad, for BART's structures and clearances are not adequate for heavy or bulky equipment (Snyder, 1981). Thus, BART should not be relied upon for emergency transport in the period immediately following the earthquake.

#### Planning Insights

Rail facilities within the urban areas surrounding the Bay will be non-operational and, accordingly, if rail transport is essential to recovery efforts, consideration must be given to selection of appropriate rail terminals where material can be off-loaded for truck, airborne, or barge transport. Railheads at Benicia and Vallejo may be most critical for movement of heavy equipment by barge to heavily damaged areas in Marin County and the San Francisco peninsula. Integrated planning needs to be undertaken for air, rail, highway, and marine transports.

## Recommended Further Work

Consideration should be given to the possibility of establishing temporary terminals following the earthquake where serviceable tracks come into the Concord and Livermore Valley areas for off-loading of major supplies and equipment. The railheads of Benicia and Vallejo should be examined to determine their adequacy for transport of heavy equipment from rail to barge.

Evaluation is needed of the relative vulnerabilities of the routes that give access to the Bay area via northern Contra Costa County. A detailed engineering and geologic examination of these routes might reveal that rail transport to a closer-in staging area near Richmond (that might also permit transfer of materials to barges) might be possible.

### RAILROADS

### MAP NOTATIONS

(See Map 1-RM)

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
R1	BART TransBay Tube <u>Closed to normal operations for over 72 hours.</u>	San Francisco/Alameda

Although the tube will not rupture, the system will be temporarily without power. Passengers will be able to walk out of the tube on foot. Hi Rail vehicles are available to pull the trains out the east end, but this could take up to 24 hours. After the trains are cleared, the Hi Rail vehicles would be able to traverse the Bay via the tube, but, as mentioned, they do not have substantial loading capacity, either for passengers or supplies. Soil conditions at the east end of the tunnel are similar to that at the east approach to the Bay Bridge, which is expected to fail

(CDOT, 1981). Both ends of the tube have flexible joints for coping with differential movement (BART exhibit, MacArthur Station, 1982).

- R2 BART Subway-SF San Francisco  
Closed.  
The subway will not be damaged extensively, but the system will be shut down indefinitely.
- R3 BART Subway-Oakland Alameda  
Closed.  
The subway will not be seriously damaged, but the system will be shut down indefinitely.
- R4 BART Elevated Sections  
Closed  
The elevated sections are designed to withstand the shaking effects of a M 8.3 earthquake on the San Andreas fault. It is highly probable, however, that throughout the system at least a few elevated spans will fail and result in closure.
- R5 BART Berkeley Hills Tunnel Alameda  
Open.  
The tunnel section will not be damaged providing there is no sympathetic movement on the Hayward fault, which traverses the west end (J. Burns, oral communication, 1981) and currently exhibits fault creep (LNG Task Force, 1980, p. III-18).
- R6 Southern Pacific-Suisun Marsh Solano  
Closed for up to 36 hours.  
The tracks were disrupted here during the 1906 event due to liquefaction and ground settlement of up to 11 feet (Youd and Hoose, 1978).
- R7 Oakland Army Terminal Switchyard Alameda  
Closed.
- R8 Oakland Naval Supply Center Switchyard Alameda  
Closed.
- R9 SP South Bay Crossing between Fremont and Redwood City Alameda/San Mateo  
Closed.

- R10 SP Commuter Station San Francisco  
Closed.
- R11 Southern Pacific Commuter Line San Mateo  
Closed.
- R12 Western Pacific and Southern Pacific Alameda  
Closed for over 72 hours.  
Sunol is the western-most access to the Bay area along this route. The tracks will be closed due to slides and bridge failures similar to those involving the highway through Niles Canyon (CDOT, 1981).
- R13 SP and A T & SF Contra Costa  
Closed for up to 36 hours.  
The westernmost access to the Bay area will be disrupted at this point along these two lines east of Martinez.
- R14 AMTRAK Passenger Station Alameda  
Closed.  
Station closed due to track disruption.
- R15 Western Pacific near San Jose State Santa Clara  
Closed.  
Northernmost access to lines in the East Bay disrupted at Coyote Creek overcrossing south of San Jose State University.
- R16 Mountain View RR Overhead Santa Clara  
Closed.  
Northernmost access to San Francisco on the peninsula disrupted by the failure of the Mountain View railroad overhead which is "substandard" (Eggleston, 1980).
- R17 Northwestern Pacific Sonoma  
Closed.  
Southernmost access to the Bay Area cut off by track disruption along the Petaluma River.
- R18 San Francisco Municipal Railway San Francisco  
Closed.  
Closed by debris and lack of electrical power.

- R19 Northwestern Pacific at Schellville Sonoma  
Closed.  
Closed by rail disruption between Schellville and San Rafael.
- R20 Southern Pacific Napa/Sonoma  
Closed.  
Closed between Napa Junction and Schellville.
- R21 Southern Pacific to Vallejo Solano/Napa  
Open.  
In wet weather, landslides may cause minor disruption of tracks in Jameson Canyon between Cordelia and Napa Valley, but otherwise the route to Mare Island Strait will be accessible.
- R22 SP spur to Camp Parks (near Pleasanton) Alameda  
Open.  
Most likely westernmost terminal on this line.
- R23 Pajaro River Bridge San Benito  
Closed.  
Northernmost access to the Bay Area via the coastal route from the south will be interrupted due to offset along the San Andreas fault as in 1906. "Its failure is anticipated in the event of an 8.3 magnitude shock" (Algermissen and others, 1972, p. 156).
- R24 Naval Weapons Station Terminal Contra Costa  
Open.  
Most likely westernmost terminal on this line.
- R25 Port Chicago Terminal Contra Costa  
Closed.  
Closed due to ground failure and disruption of rails.
- R26 SP and WP between San Jose and Oakland Alameda  
Closed.  
Closed for repairs along the southern section.

- R27 SP between San Jose and San Leandro Alameda  
Closed.  
Closed due to ground failure and track disruption.
- R28 Mare Island Bridge Napa  
Closed.  
Closed due to failure of bridge.
- R29 Mare Island Strait Terminal Napa  
Open.  
Southernmost access to the Bay Area along this line. Open and usable for marine transport, although access depends upon assumed minor problems along route through Jameson Canyon (R21).



THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.





Compiled by  
James F. Davis, John H. Barnett, Glenn Borchardt,  
James E. Kohle, Salam J. Rica and Michael A. Silao



## EARTHQUAKE PLANNING SCENARIO

For a Magnitude 8.3 Earthquake on the San Andreas Fault in  
the San Francisco Bay Area

### RAILROADS AND MARINE FACILITIES

#### RAILROADS

- (R21) — Location of damage assessment (see text for details) — M7
- WP — Western Pacific Railroad Co
- SP — Southern Pacific Trans Co
- AT&SF — Atchison Topeka and Santa Fe Railway
- NWP — Northwestern Pacific Railroad
- Bay Area Rapid Transit (BART)
- Location of Main Line Closure

1982

#### EXPLANATION

#### MARINE FACILITIES

- 42 — Commercial Vessel
- 45 — Pleasure Craft
- 53 — Military

||||| — Surface Fault Rupture for Scenario Earthquake

Bayside facilities at San Francisco, Oakland, Richardson Bay, Richmond, and Carquinez Straits will be accessible to tug and barge traffic.

**THIS MAP IS INTENDED FOR EARTHQUAKE PLANNING PURPOSES ONLY**

\* IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:

1. A PARTICULAR EARTHQUAKE OCCURS
2. VARIOUS LOCATIONS IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF BUILDING OR GROUND FAILURE
3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT

\* THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS AN APPROPRIATE ENGINEERING EVALUATION FOR THE MOST RAPID DAMAGE ASSESSMENT AND STRATEGIC REPLACEMENT BY THE STATE EMERGENCY TASK FORCE. IN THIS PLANNING AREA THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTED BEHAVIOR OF THE EARTHQUAKE. HOWEVER, SEVERAL DIFFERENT BUT CONSISTENTLY TESTED AND ANALYZED YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACULTIES THAT ARE PARTICULARLY SUSCEPTIBLE TO DAMAGE INCLUDE A DETAILED GEOTECHNICAL STUDY.

\* THE DAMAGE ASSESSMENTS ARE BASED UPON THE EARTHQUAKE SCENARIO ASSUMED AS A HYPOTHETICAL EARTHQUAKE OF INCONSIDERABLE MAGNITUDE ON A FRACTURE LOCATION ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WHICH RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.

KILOMETERS  
0 2 4 6 8 10 12  
MILES  
0 2 4 6 8 10 12  
10 20 30 (X1000) FEET

#### PLANNING AREA 1 SAN ANDREAS FAULT (North)



#### KEY TO EARTHQUAKE PLANNING SCENARIO MAPS

##### Map Designation

##### Subject

Seismic Intensity Distribution

##### Lifeline Damage Assessments

- |      |                                 |
|------|---------------------------------|
| 1-HA | Highways and Airports           |
| 1-RM | Railroads and Marine Facilities |
| 1-C  | Communication                   |
| 1-W  | Water Supply and Waste Disposal |
| 1-E  | Electrical Power                |
| 1-G  | Natural Gas                     |
| 1-P  | Petroleum Fuels                 |



## EARTHQUAKE PLANNING SCENARIO: MARINE FACILITIES

### Map 1-RM

#### General Pattern

The majority of the docks around the Bay are supported on piles and these should not be significantly damaged. Operations at the container terminals, however, which are generally constructed on fill, will be seriously impaired. Disruption of rail facilities, impaired highway access, toppling of cranes, pipeline ruptures, and similar problems will be controlling factors affecting the use of the various port facilities.

The use of barges to transport heavy equipment and supplies to heavily damaged areas will be dependent on the integrity of docks. The major bayside facilities at San Francisco, Oakland, Richardson Bay, Richmond, and the Carquinez Straits should be accessible for tug and barge operations. South of Hunters Point and San Leandro, all facilities would be inaccessible to larger vessels including tug and barge traffic.

#### Description

According to Algermissen and others (1972, p. 170), during the 1906 earthquake "performance of the pile-supported docks along San Francisco's waterfront was excellent, although the soil in some fills nearby settled in terms of feet." Quay wall facilities, however, have not performed as well. (A quay

wall is a waterfront wall with an earthen fill behind. Failures of quay walls have generally been attributed to liquefaction of the soils behind the quay walls, forcing the walls outward).

Most of the docks in the Bay area are pile supported and, overall, marine facilities are not expected to be greatly affected insofar as the pile-supported docks are concerned. However, some cranes will be thrown off their rails. Pipelines from storage tanks to docks will be ruptured where they cross areas of structurally poor ground in the vicinity of the docks. Restricted access to docks due to damage to freeways and nearby surface streets will be more common than significant damage to the pile-supported docks.

Bayside port facilities at San Francisco, Oakland, Richardson Bay, Richmond, and Carquinez Straits will be generally accessible to tug and barge traffic. Marine facilities south of Hunters Point on the peninsula and San Leandro in the East Bay will, however, be inaccessible to both tug and barge movement.

Algermissen and others (1972) concluded that "The overall effect is not expected to impair the efficiency of the study area port facilities by more than 15%."

The following comments were developed for this evaluation by the Marine Transport Committee of the Governor's Emergency Task Force on Earthquake Preparedness:

Regardless of the specific area or time of day, the estimates set forth in this section should be valid due to the basic nature of maritime activity. It is expected that damage to most dry cargo port facilities and marinas should be less than in previous severe quakes due to modern building techniques and facility spacing. However, the failure of quay walls and lateral displacement at container terminals could be expected to be severe so that operations would be drastically curtailed. Inasmuch as these facilities are constructed on filled land, cranes could topple, tracks could become misaligned, and automatic shore-side container storage and distribution cells could be warped.

Most vessel cargo transfer operations are self-contained so that, except for container ships without cranes, cargo operations could be continued after a major earthquake to the limit of shore-side support. The controlling factors will be restricted road access, pipeline breaks, and fill land failures in the vicinity of piers and terminals.

At liquid handling facilities no significant damage to either vessels or piers is expected. However, shore pipeline failures could be expected, and even if no failure occurred, cargo operations will cease until all systems have been thoroughly checked.

Generally speaking, dry bulk cargo and container operations could be expected to come to a halt due to access problems and shifts in land fill areas. Over a short period, or even a moderately long period, this shutdown would have no significant effect on life-line functions in an earthquake impacted area due to the indirect consumer nature of modern inbound cargos.

Vessels destined for an impacted port area would be diverted at sea to alternate port facilities or delayed in arrival to an impacted area.

Small craft facilities may suffer minor damage through ruptured pipelines and slides under piers from adjacent fill land. The most significant impairment would probably be closure of waterways in some areas. In the South San Francisco Bay and the southern half of the East Bay areas, dredged channels could be expected to shift so the small craft in the vicinity of Redwood City and south, and craft in the Alameda-San Leandro areas would be confronted with blocked channels. The North Bay and nearby Delta areas are expected to be accessible by small craft.

#### Planning Insights

The use of tugs and barges to transport heavy equipment and supplies to the San Francisco and Marin peninsulas appears to be a viable emergency response procedure. Assuming that most of the docks in the heavily damaged areas will be usable, availability of emergency power and off-loading capabilities will be requisite. Use of barge transport will necessitate coordinated planning for loading of needed material at a dockside facility adjacent to a marshalling depot and/or railhead with corresponding loading capabilities.

Transport of emergency personnel and equipment into these same heavily damaged areas and evacuation of the injured will be a vital function of the numerous Bay ferries. Planning should consider the most feasible terminals

(on both ends) in order to complete these missions. Again, coordination with other ground transport capabilities will be required in order to effect efficient transfers.

The utilization of privately-owned vessels to augment this supply and evacuation effort is appropriate. Practical education, planning, and training programs to implement this participation should be initiated.

#### Recommended Further Work

The various roles that marine transport can assume in the emergency response efforts and the extent of marine transport resources should be determined. The port facilities in the areas of expected heavy casualties/damage should be assessed, and locations with suitable land-access and loading capabilities, that are most likely to be available for post-earthquake access to marine transport, should be selected. Port facilities outside the heavily damaged areas should be coordinated with ground transport to identify the most efficient means of transporting the injured, materiel, etc.

The capabilities of private vessels and the potential roles of their operators should be determined. Appropriate training programs should be established to ensure the emergency-response effectiveness of this resource.

MARINE FACILITIES

Map Notations

(See Map 1-RM.)

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
M1	San Francisco Waterfront	San Francisco
	Along the San Francisco waterfront there will be numerous failures of quay walls, disruption of waterfront rail facilities, derailment of cranes and railroad cars, ruptured pipelines, etc. Docks are generally pile-supported, however, and most will be accessible for emergency response operations. Access to the waterfront will be impaired by debris and major damage along many approach streets.	
M2	Oakland Inner Harbor-Alameda	Alameda
	Port facilities in the Oakland Inner Harbor and Alameda will experience moderate damage of the same nature as enumerated in note M1 above. Disruption of both rail and road access to Alameda and its port facilities will be a controlling factor in resumption of operations.	
M3	Oakland Outer/Middle Harbors	Alameda
	Operations at the large cargo terminals located in the Oakland Outer and Middle Harbor areas will be significantly disrupted. Built on fill of questionable merit, these areas will experience ground failures causing considerable disruption to the piers, the extensive rail systems, cranes, and warehouse facilities. Rail access to the area is assumed to be unavailable for at least 72 hours and the limited vehicular access will be further restricted by heavy damage to the nearby freeway system.	
M4	Richmond	Contra Costa
	Port facilities at Richmond will sustain localized ground failures disrupting rail and street access. Damage to oil pipeline and storage facilities near the harbor poses a threat of contamination and fire.	
M5	Alameda-San Leandro	Alameda
	Small craft facilities in the San Leandro and Alameda areas will be closed by blocked channels.	

- M6 South Bay San Mateo-Santa Clara  
All marine facilities at Redwood Creek, Palo Alto, and Alviso Channel will be inoperable and inaccessible.
- M7 Petaluma River Sonoma  
The Petaluma River will be blocked.
- M8 Benicia-Vallejo Solano  
Damage to marine facilities and appurtenant rail connections at Benicia and Vallejo will be minor. Allowing 36 hours to accomplish necessary repairs to the main line tracks across Suisun Marsh (see note R6) and minor repairs due to landslides in Jameson Canyon (see note R21) rail service to these two Bayside facilities will be available.



EARTHQUAKE PLANNING SCENARIO: COMMUNICATIONS

Map 1-C

The following discussion of communication systems was prepared by the Communications Advisory Committee of the Governor's Emergency Task Force on Earthquake Preparedness. James Cotter is principally responsible for development of this analysis.

General Pattern

Telephone communications will be adversely affected due to overloading resulting from post-earthquake calls within the area and from the outside. This situation will be further complicated by physical damage to equipment due to ground shaking, loss of service due to loss of electrical power and subsequent failure of some auxiliary power sources.

Not all of the systems in the region are set up to process emergency calls automatically on previously established priority bases. Thus, overloading of equipment still in service could be very significant.

Telecommunications systems are composed of many subsystems, each interconnected and interdependent. A radio network, for example, may use a combination of telephone lines, microwave circuits, satellite interfaces, underground and overhead cables, and secondary radio paths. The failure of one link in this electronic "chain" can effectively disable a large portion of the

system. The post-earthquake communications scenario has been treated as a matrix of events that would reduce the effectiveness of systems rather than completely destroy them. It is also assumed that portions of many systems could be repaired to a limited extent by resourceful operators. Criteria such as geographical coverage, the number of system elements, and functional integration were considered in estimating the post-earthquake effectiveness of a particular system. With the maximum capacity of any system represented as 100%, most systems operate at approximately 85% because of ongoing maintenance. The effects of the scenario earthquake must be applied to this ratio to determine the degree to which the overall effectiveness is reduced. "Effectiveness" is defined as the ability of a system to perform to its design limits and provide the intended service.

#### Description

The communications scenario is described in subsections, each of which treats one of the following generic systems: telephone, radio, microwave, satellite, data, and commercial broadcast.

#### Telephone Systems

##### Map No. 1-C

Telephone systems are mutually interdependent because of a vast, complex, interconnected network, yet they are also self-supporting on a local basis.

One service provided by the telephone companies is intraexchange traffic, i.e., calls between telephones within the area served by a single central office or "exchange." Another is interexchange service where calls are switched between two central offices within a region. There is third service, similar to interexchange, where calls are routed to a long-distance facility. Each of these services can be provided by a variety of system configurations.

The telephone companies have installation standards that minimize earthquake damage. They also have emergency mobilization plans and have exercised these plans effectively. Nonetheless, there has not been a disaster in modern times of the magnitude here addressed. It is therefore quite difficult to forecast the detailed effects of a major earthquake on the telephone systems. There are, however, a number of outcomes that can be anticipated: hardware damage such as underground cable failure in areas of liquefaction, damage to surface cable carriers, system-call saturation during post-earthquake recovery, and repair-access problems.

Our evaluation of system performance takes into account the likelihood of any or all of these events occurring and subjectively applies this evaluation to an effectiveness scale, as shown on Map 1-C. The effectiveness scale essentially is an attempt to quantify the ability of public safety agencies to conduct recovery efforts by using the telephone system. It is not directly applicable to the general performance of the system nor to the public's ability to use the system.

The effectiveness scale has then been applied to a three-day time frame. Four patterns of effectiveness over time were distinguished and used as the

basis for zoning the study area (Zones A, B, C, and D on Map 1-C). Zone A will fair best and Zone D the worst. The definitions of these zones are based upon a number of factors: past telephone performance in disaster situations, casualty projections, population density and demography, post-earthquake transportation evaluations, the probable performance of commercial power facilities, and any known site-specific technical considerations. No attempt has been made to separately evaluate each of several hundred telephone facilities.

Some basic assumptions have been made: (1) the shaking intensities used in this scenario were projected by the CDMG as shown on Map 1-S; (2) areas experiencing a shaking intensity of 8 (R-F) or greater will have significant hardware damage although such damage would be fairly localized and not on a large regional scale; (3) some underground cables will be damaged by ground failure, but not in sufficient number to preclude switching alternatives; (4) most predesignated public safety circuits will receive priority restoration; (5) most telephone company backup power provisions will be functional; (6) the long distance network, although difficult to access, will remain generically stable; (7) interexchange facilities will be difficult to access, but would remain essentially intact; (8) shortly after the event, numerous relatively simple failures will occur that, coupled with intense call saturation, will effectively disable the telephone networks for approximately 6 hours; and (9) for planning purposes, the event will be considered to occur after normal business hours.

## Specific Vulnerabilities

The most vulnerable aspects of telephone systems are the computers used to switch message traffic. All are environmentally sensitive and may be mounted on false floors. The performance of these computers is not easily associated with a time frame because of the long-term effect of environmental control failure. Call saturation, resulting in local station and all-trunks busy, is the most obvious system access problem that can be predicted. Most telephone systems presently are working at or near capacity for normal traffic; the systems will be saturated easily by the sudden activity following an earthquake. Most exchanges, however, have the capability through the switching computers to control system load by limiting access to only predesignated circuits. Another potential problem is emergency power. While the telephone systems work mostly on battery power, with propane or gasoline backup generators to provide charging, the generators depend upon batteries for starting and fuel lines and tanks for continued operation. If emergency power does fail, system performance on batteries will degrade at a significant rate.

Assuming the earthquake will occur outside normal business hours, a number of staffing dimensions must be considered when evaluating telephone system performance in the scenario. The first concern of telephone company employees will be assessment of their own immediate condition; second, they will be concerned about their families and friends. A small percentage of staff will leave their jobs to ameliorate the effects of the disaster in their personal lives. Some of the employees will suffer casualties and will be confronted with mobility problems on streets and highways. The repair-vehicle fleets will probably be generally inaccessible to staff for several hours and, in

some cases, will probably be immobilized by facility failure. In systems that must revert to operator intercept, where all dialed calls go to an operator, fatigue would curtail effectiveness. The same fatigue will apply to central office personnel. Further, the telephone companies will probably be without upper-echelon management and supervisory personnel during the first hours following an earthquake; the transportation situation may be magnified because these persons often live further from their office than journeymen. Another portion of staff will be unavailable because of normal vacation and illness.

It is likely that telephone company mobilization plans will be difficult to implement because of the exercise of other priorities by local and State government as well as limited transportation. The thousands of repair parts and materials needed for recovery may also be difficult to obtain.

In summary, the effects of a major earthquake on telephone systems will be dynamic and dependent upon a multitude of events rather than upon any single factor. The overall evaluation, thus, is highly subjective and must be considered only as a public safety planning document.

#### Post Earthquake Telephone Systems Effectiveness

San Francisco Bay area: The volume of calls that would follow the scenario earthquake if it occurred after normal business hours would not be as heavy and paralyzing to the telephone system in San Francisco, with its high business concentration, as it would be during that time period in more heavily residential areas. But, although the system in San Francisco has line access

control, it is more isolated systemically than the Los Angeles metropolitan area, for example, and is very dependent upon a few telecommunications arteries. Key system facilities are located near the San Andreas fault in areas projected to experience intense shaking. It is likely that the telephone systems in and to the south of San Francisco will have systemic failures not readily compensated by alternative traffic routing. It is also probable that the recovery effort will be delayed because many company employees live outside the city limits and important transportation routes will be impassable.

There is a very good system in San Francisco for identifying important public safety telephone circuits. These dedicated lines should be minimally disrupted. The effectiveness rating, however, is quite low because local agencies will presumably require a great amount of outside assistance; the ability of the telephone system to meet these needs will be limited.

In Marin County, telephone system vulnerability was evidenced by the 1982 storms. The geography and demography is such that alternate routing is limited. Key central offices are located in areas expected to suffer severe shaking and ground failure. Many access routes will be impassable. This area is particularly susceptible to underground cable and surface cable carrier failure. Line load control is available but would not alleviate other systemic problems.

Although the Oakland/East Bay area has a substantial number of telephone facilities located in intense shaking and high probability of ground failure, access to accomplish repairs should not be a major problem. Further, there are several switching options. Systems in this region have line access control and predesignated public safety circuits.

Systems in the San Jose/South Bay area will experience severe shaking intensities and have extensive areas of potential ground failure. Despite this, repair staff should be in reasonable proximity to their offices with fewer access problems than adjacent areas. The telephone systems will be saturated but have designated circuits and line-load controls. Because of shaking patterns corresponding with key facility locations, the South Bay area is likely to experience complete localized telephone failures on a block-by-block basis.

#### Radio Systems

Radio systems will generally operate at 40% effectiveness for the first 12 hours after the earthquake, increase to 50% for the second 12 hours, then begin a slow decline to approximately 40% within 36 hours. The long-term implications are that individual systems gradually will become less useful to the overall recovery effort when supplanted by systems relocated from outside the disaster area. It is unlikely that public safety radio systems would become saturated with non-critical communications from mobile units; it is clear, however, that radio traffic densities on redundant (non-emergency designated) channels would increase, particularly when remote base station and repeater failures would tend to limit the number of redundant channels available. Nonetheless, after 12 hours, at which time the number of operable units will have declined (with exhaustion of emergency power fuel) and recovery efforts will have restored some order, the radio traffic density problem will ease.

For each of the various components of a radio system, we anticipate specific effects under the scenario. These effects are described in the following component discussions:

#### Radio Control Consoles

Radio control consoles generally fall into three categories: self-contained tabletop base stations, tabletop control consoles for remote base stations, and full-size consoles using electronic circuitry (often very sophisticated) to control remote base stations. Both tabletop models are vulnerable to earthquake damage because they are rarely secured. While the self-contained station is more likely to remain functional than other types (since it doesn't rely on remote equipment), it is often not supplied with emergency backup power. System designs using control stations normally have such backup power provisions. Control consoles rely either upon telephone or microwave circuits to access remote equipment. We do not anticipate continued microwave operation and cannot recommend telephone lines as an alternative, though such dedicated control circuits are more likely to remain functional than conventional telephone service. Sophisticated consoles are better protected against physical damage and normally have emergency power available, but they rely upon telephone and microwave circuits and have an added problem of repair complexity. If a key component of a large console fails, many radio subsystems would be fragmented, placing the burden of communications on outlying stations more vulnerable to earthquake damage. Further, software-based consoles would probably face additional complications within 12 hours. We estimate that self-contained tabletop base stations would be 40% effective, tabletop control consoles 55% effective, and large consoles 50% effective.

## Base Stations

Radio base stations are often located on the roof of the same building housing the control console. In such cases, the condition of the building would determine post-earthquake performance. Even if cabling between the two units was to fail, base stations can be operated on-site via a microphone provided within the equipment cabinet. Dispatchers, however, are not normally aware of this and even more rarely have the key needed to gain access to the microphone. Remote base stations, located in a different building or in a mountain-top radio vault are subject to potential structural damage. Stations atop buildings are probably less vulnerable to wiring and component malfunctions than other installations but share the threat of telephone circuit interruption. We estimate that effectiveness will be 70% for local base station installations and 55% for remote stations, declining after 12 hours as emergency-power fuel supplies become exhausted.

## Repeaters (mobile relays)

Repeaters are not dependent upon control circuits and are normally provided with backup emergency power. Located atop mountains, they are vulnerable to structural, electric, and other internal damage from heat buildup. Depending upon the proximity of the fault source, they are more likely to experience technical problems than base stations. We estimate that repeaters will be 60% effective, declining as emergency power supplies are exhausted and technical problems develop, becoming 40% effective after 24 hours.

## Antennas

We do not believe that antennas will fail on a large scale. Antennas and related structures should remain 70% effective.

## Hand-held and Portable Two-way Radios

It is probable that hand-held radios will be valuable to field units during the first 12 hours after a major earthquake, particularly in a system that does not use repeaters. In any case, there are problems with charging and distributing batteries. We do not consider this kind of portable equipment to be of any significant benefit to the overall recovery effort after 12 hours per battery that is available to each unit; that is, a unit equipped with one fully-charged backup battery would be operational for 24 hours total.

## Mobile (Vehicular) Radios

Assuming that gasoline supplies will be scarce and that transportation systems would be disrupted, the value of mobile radios would coincide with their distribution at the time of the disaster. We estimate that, functionally, higher-powered mobile radios would be 75% effective for the first 12 hours, declining thereafter because of fuel and battery problems. At the same time, the mobile radio system as a whole would doubtlessly be compromised because of the distribution of the units. It is more realistic to consider mobile radios approximately 60% effective initially, declining thereafter.

This estimate is for public agencies; should an earthquake occur after working hours, the effect on commercial systems will be more severe.

#### HAM and Other Amateur Radio

Amateur radio stations are subject to the hazards outlined earlier. A particularly vulnerable point is emergency power; most home base stations do not have backup facilities. Nonetheless, there is an extensive vehicular radio and repeater system in the amateur radio service. Much of the first post-disaster intelligence would come from this private sector resource and, in some cases, radio amateurs may be the only means of reaching the outside world. The amateur radio service should remain more than 50% effective because of pre-organization and the long distance capabilities of the equipment.

#### Citizens' Band Radio

We do not believe that CB radios will have an appreciable effectiveness in the public agency recovery effort, although there would be some post-disaster intelligence value. The units are too low-powered and are susceptible to frequency saturation. It is possible that CB "zones," each zone using a predesignated channel, could be established within neighborhoods for the self-help effort. Being the most accessible two-way communications resource for the general public, Citizens' Band would be a significant element in the smaller recovery "cells" if users receive prior education and orientation.

## Radio Common Carrier (RCC)

Radio common carriers will be subject to the events noted earlier for public agencies.

### Aircraft and Marine Radio Communication

Either radio service will be at least 80% effective provided that airfields are nominally accessible and there are no severe conditions that would significantly disrupt moored maritime resources. While there are many potentials within either service for providing good quality emergency communications, existing land-based systems are completely incompatible. The overall effectiveness of marine radio must be equated to prior frequency coordination for marine transport systems. The relative importance of these radio services would increase as recovery efforts commence.

### Microwave Systems

Microwave systems have all the vulnerability of other radio systems plus additional problems related to narrow frequency tolerances, softwarecontrolled switching systems, and sensitive gain (directionability) tolerances. Additionally, many systems are not point-to-point but are linked through several points. The likelihood of failure in any one link is fairly great; therefore, we feel that microwave systems, with the possible exception of telephone microwave systems, will not extend beyond the affected disaster regions. Some

circuits may remain operable on a point-to-point basis. It is estimated that most microwave systems would be 30% effective or less.

#### Satellite Communications

Remote satellite terminals relying upon telephone or microwave circuits will be 40% to 50% effective, similar to radio base stations. Stationproximate terminals will have a greater likelihood of survival approximating 70%. Because the satellites themselves are impervious to earthquake damage, they are one of the most significant resources for supplanted communications systems.

#### Data Communications

Communications systems used to support computers will be 40% effective. When facilities are not physically damaged, air conditioning and environmental control systems failures may gradually reduce effectiveness.

#### Commercial Broadcasters

Some commercial stations generally will be able to provide emergency public information to the stricken area.

## Medical Services Radio Systems

The VHF medical services radio frequencies are crowded and poorly coordinated. UHF repeater systems, while less saturated, are more vulnerable to damage and failure. There are insufficient channels dedicated to telemetry; a large number of casualties could cause saturation of the channels and make them virtually useless. Further, the hospital-to-hospital systems are expected to fail. We do not anticipate the continued function of medical radio services to an appreciable level of effectiveness.

### General Comments on the Communications Scenario

The lack of emergency power has been the primary cause of communications failure in past disasters. Poor installation practices and inadequate preventative maintenance of backup power equipment contribute to a high failure rate. The presumed scarcity of propane and gasoline after a major earthquake will strictly limit the viability of surviving communications sites.

The availability of repair parts and ability to transport them are other factors when considering both shortand long-range implications. We believe that supplanted communications systems will be needed as local systems suffer earthquake-caused and normal equipment malfunctions for which there are no repair parts.

The current state of technology is such that communications technicians have specialized areas of expertise. The tools, test equipment, and repair

parts they use are often suited only for the particular type of equipment a particular specialist works with. As a result, one specialist would have difficulty repairing equipment that is outside his area of specialization. Most radio technicians, for example, are unable to repair microwave equipment, military staff are unable to repair some types of public radio equipment, and microwave specialists are unable to assist telephone staff. This problem is further compounded by the unique characteristics of many systems otherwise generically related. Depending on the time the earthquake occurs, the number of technical staff available for repair services could range between 20% and 50% of the total for the first 24 hours. If it occurs between 1600 and 0600 hours, approximately 20% may be available in the first 24 hours, 40% in 48 hours, and 70% in 72 hours. If the disaster occurs between 0600 hours and 1600 hours, some personnel would be disabled, isolated, or occupied with verifying the status of their families: 50% will be available for the first 24 hours, 60% in 48 hours, and 70% in 72 hours. The effectiveness of technical personnel is severely affected by the availability of transportation. In many cases, for example, helicopters would be needed for access to remote sites. Technical staff would only be able to support the continued operation of systems at a level of post-disaster effectiveness. After approximately one week, system performance would begin improving.

The regulation of communications has necessarily separated users to avoid mutual interference. One result of this separation is mutual exclusion. Except in rare circumstances, two adjacent communications systems are physically or functionally incompatible. The greatest danger to a post-earthquake recovery effort is the absence of adequate interface between systems. This applies equally to local systems and systems drawn from outside the disaster area.

## Planning Insights

A general communication plan should be developed for use, following the earthquake, by appropriate agencies and personnel with emergency-response roles. This plan should anticipate the needs of the most vital parties.

Reliance on emergency telephone communications should be kept at a minimum. A strategy should be developed for communication to the general public which relies upon the capabilities of surviving commercial radio and television stations.

## Recommended Further Work

An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan.

A survey of existing critical communications facilities should be undertaken by structural engineers leading to development of improved equipment installation standards.

There is need for a continuing technical examination and overview of alternative means of communication with the object of working out regional plans for communication between emergency workers and the public at large. There is a need for a technical examination of alternative means of communication, e.g., satellite.

COMMUNICATIONS

MAP NOTATIONS

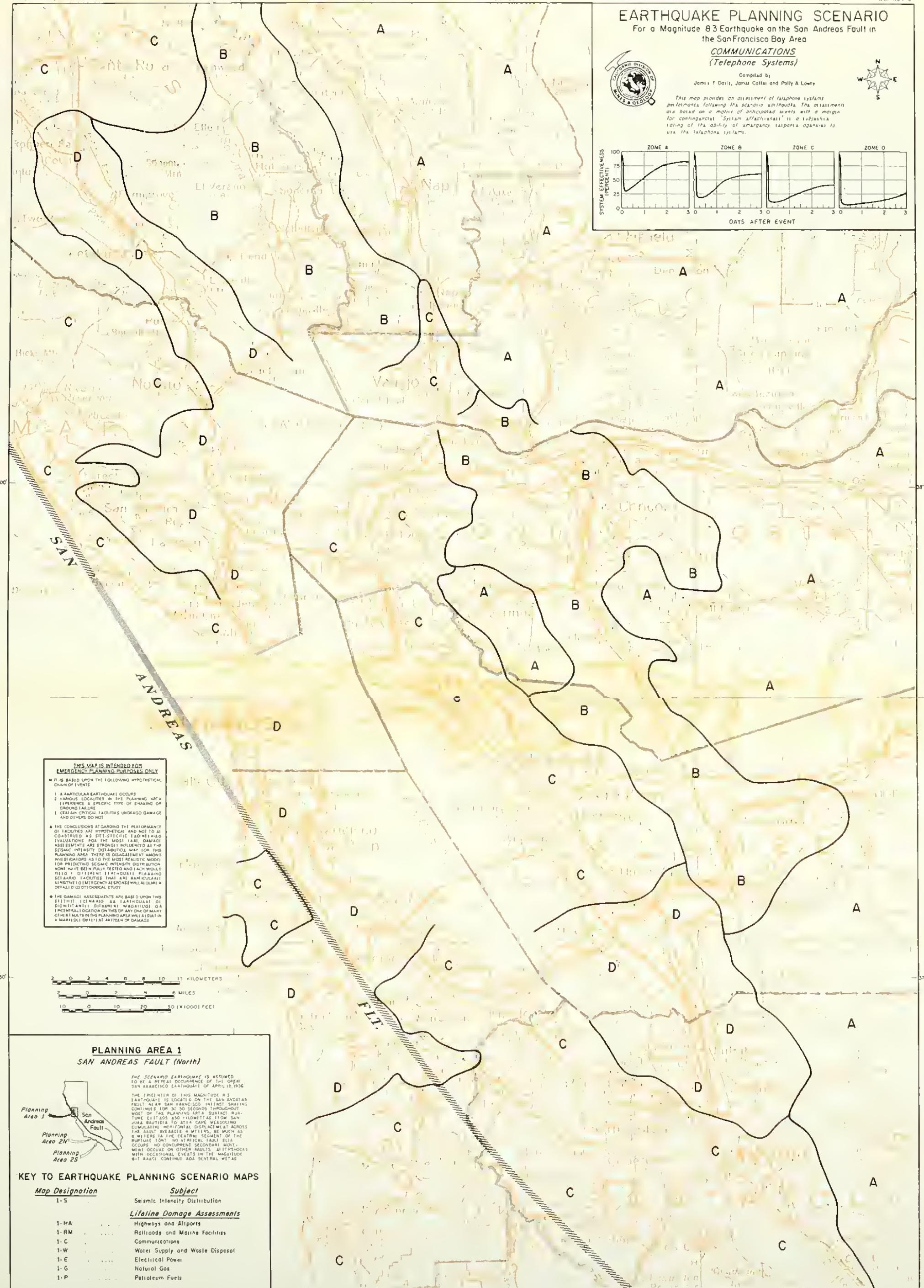
(See Map 1-C.)

On Map 1-C, there are no notations for specific sites or facilities. As explained on the map, areas are zoned according to the level of telephone system effectiveness expected during the first three days following the earthquake. Four levels of expected effectiveness, ranging from highest to lowest, are distinguished. Zone A areas are those expected to have the highest levels of post-earthquake effectiveness, and Zone D areas, the lowest.

THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







EARTHQUAKE PLANNING SCENARIO: WATER SUPPLY

AND WASTE DISPOSAL

Map 1-W

General Pattern

Several of the major aqueducts that deliver imported water to various segments of the planning area will sustain damage causing temporary interruptions in supply. The numerous major reservoirs in the area provide ample storage to meet demands during the time required for repairs. However, impairments to water transmission lines, local storage reservoirs, and pumping plants, as well as local distribution systems, will affect water availability and pressure. The absence of electrical power for extended periods will in some areas preclude water deliveries where pumping is necessary, even though conveyance facilities may be intact. Many areas could be dependent on tanker trucks to provide their basic needs. For planning purposes, one major dam (Lower Crystal Springs Dam, in San Mateo County) is assumed to incur major damage necessitating downstream evacuation procedures.

Sewage collection systems will sustain widespread damage, particularly in the low-lying areas nearer the Bay. The many sewage treatment facilities also located in structurally poor ground adjacent to the Bay will be damaged and experience electrical power losses resulting in discharge of raw sewage into the Bay.

### Description

The water supply to the Bay area is provided by several systems. The vulnerability of each of these systems must be appraised holistically. That is, the individual component parts of each system -- the water source, aqueducts, local storage reservoirs (including dams), pumping stations, transmission lines, and local distribution lines -- each must be viewed in the context of the entire system and its performance. Impairment of any one of these major elements could seriously compromise the performance of the whole system. For emergency planning purposes, it is important to recognize that this domino effect makes the system's overall performance more vulnerable than casual examination of individual components might suggest.

Several major aqueducts import water to various parts of the planning area and most of these are, to some degree, vulnerable to damage as a result of the scenario earthquake. The City of San Francisco and a number of municipal utilities in San Mateo, Santa Clara, and Alameda counties receive water imported from the Tuolumne River in the western Sierra Nevada via the Hetch Hetchy Aqueduct, operated by the City of San Francisco. The South Bay area and Livermore Valley has received imported water from the South Bay Aqueduct since 1965, and in the mid-1980s Santa Clara County will receive its first water deliveries from the U.S. Bureau of Reclamations (U.S.B.R.) San Felipe Project (water from San Luis Reservoir via Pacheco Tunnel). Most of the East Bay also receives its water from the Sierra Nevada via the East Bay Municipal Utility District's Mokelumne Aqueduct. Contra Costa County imports water via the Contra Costa Canal from the San Joaquin delta.

In the North Bay, southern Sonoma County is dependent upon the Petaluma and Sonoma Aqueducts to deliver water south from the Russian River. Southern Solano County receives water via U.S.B.R.'s Putah South Canal, from which water is delivered to southern Napa County through facilities of the North Bay Aqueduct. Marin County is largely dependent upon locally developed water storage facilities.

Any one, or all, of these larger aqueducts could be ruptured or damaged as a result of the scenario earthquake. Significant failures could result in flooding, erosion, and other secondary damage that could compound efforts to consummate repairs. For planning purposes, it has been assumed that the Hetch Hetchy, Mokelumne, Petaluma, and South Bay Aqueducts will sustain some damage. Damage to these and certain other critical water facilities are described in the notations for Map 1-W.

While there should be ample water storage in the numerous Bay area reservoirs to satisfy all water demands during the period while aqueduct repairs are in progress, the distribution system may be such that deliveries to all service areas may not be possible. In the short-term, the loss of electrical power will prevent pumping water to many areas at higher elevations and, thus, only undamaged gravity systems will be able to provide a continuous water supply. This may be most critical on the Marin and San Francisco peninsulas where a substantial population resides at higher elevations and where the time required to restore electrical power may be most lengthy.

Of all the aqueduct systems, the Hetch Hetchy Aqueduct is regarded as the most critical from the standpoint of a large dependent population and vulnerability to damage. The location of the Hetch Hetchy Aqueducts is shown on

Map 1-W. Damage has been assumed at three general locations where the Aqueducts cross the South Bay. Hetch Hetchy water is stored at San Andreas Lake and Crystal Springs Reservoir, both on the San Andreas fault. Water is then transmitted through several large pipelines to storage facilities in the City.

The 1906 earthquake provided an example of the performance of these facilities that might be expected from another comparable event (as assumed in this scenario), for most of the present facilities follow the same routes as in 1906.

Algermissen and others (1972, p. 175) conclude that "The Hetch Hetchy aqueducts can be reasonably expected to deliver water to the peninsula reservoirs, and these reservoirs can be expected to remain intact. Quick repairable damage is likely where one conduit enters an underwater crossing of San Francisco Bay. For planning purposes, half of the aqueduct supply from the San Andreas and Crystal Springs reservoirs should be assumed to be out of service for a week; however, as in 1906, the storage reservoirs located in San Francisco will function." In general, we concur with these NOAA conclusions.

#### Water Storage Reservoirs

Catastrophic failure of a major dam as a result of the scenario earthquake is regarded as unlikely. Current design and construction practices, and on-going programs of review, modification, or total reconstruction of existing dams are intended to ensure that all dams are capable of withstanding the Maximum Credible Earthquake (MCE) for the site. For the purposes of emergency

planning, however, it is prudent to consider that one major dam within the study area will sustain damage affecting its integrity. For this scenario, it has been assumed that Lower Crystal Springs Dam develops significant leakage necessitating evacuation of the downstream population.

Lower Crystal Springs Dam is a 140-foot high concrete gravity dam constructed in 1888. Storage capacity is 54,000 acre-feet. Though the structure is located within a few hundred feet of the 1906 surface rupture it survived that earthquake without damage.

Carrying the assumption of leakage of Lower Crystal Springs Dam to the extreme, one could postulate the necessity to rapidly and totally drain the reservoir. Emergency planners should also consider the ramifications of this loss of storage on water operations.

#### Distribution System, Including Reservoirs, Pumping Plants and Distribution Pipelines.

It is expected that distribution reservoirs will suffer moderate damage: underground excavated type reservoirs, with column-support roofs, could suffer extensive roof collapse; for tank-type reservoirs of concrete construction, pipeline connections and surface damage to the shell are expected; distribution reservoirs of welded or bolted steel construction will suffer little damage, but connections will be severed in some cases. The damage to distribution storage will be significant, primarily at connections, and will likely lead to early loss of storage (Finlayson, 1982).

Pumping Plants are generally compact structures and, with the exception of related electrical equipment and transformers, will probably not suffer as much damage as the reservoirs. Large pumping plants will suffer damage closely related to the materials in which they were constructed, and damage will be primarily related to pipeline rupture and transformer damage.

Distribution Pipelines vary from 2 inches to 54 inches or more in diameter. Pipe materials vary from cast iron to welded steel and asbestos cement to a variety of plastic materials. The damage to distribution pipelines is expected to vary with pipe material, soil type, design installation practices, and shaking intensity. It is anticipated that all water systems within the region will suffer some damage. Depending upon local conditions, the population impact may be small, or catastrophic. In areas of intense shaking and/or ground failure it will not be unusual to find that there are 2 to 4 main breaks in every block where cast iron or asbestos cement pipe is used. Where such general damage to the water distribution system occurs it will be vital to repair water mains at the lowest topographic point first, and work uphill so that broken sewers in the same areas do not contaminate still broken water lines. The difficulty in determining the extent of danger to the distribution system is that leaks may not be locatable until water pressure is restored. For this reason it will take weeks to repair damage in densely populated areas. Fresh water for domestic purposes will have to be supplied by tankers to affected neighborhoods. Firefighting efforts will in some areas be seriously hampered during the 72-hour period.

Algermissen and others (1972, pg. 175) concluded that "Distribution system damage and water outages within San Francisco will be heavily accentuated in

the structurally poor ground areas which border the Bay in an irregular fashion, just as occurred in 1906. However, the anticipated good use of improved valving systems is expected to substantially reduce the loss of water due to broken mains. Similar water outages can be expected along all of the industrial and residential regions within the structurally poor ground areas along the Bay from San Francisco to San Jose. Elsewhere, the water distribution system is expected to remain mostly intact, and significant outages will be few and controllable, commensurate with availability of spare pipe, fittings, and accessibility. For scenario purposes, 90% of the water outages in the structurally poor ground areas should be restored within 3 weeks by above ground piping similar to that which was used in San Fernando.

Damage to facilities in counties other than San Francisco, Santa Clara, San Mateo, and Marin is expected to be nominal."

#### Water Treatment Plants

Treatment plant facilities will suffer damage, primarily where large pipelines connect with concrete structures and where pre-1960 concrete construction does not involve adequate concrete column tie to floor and roof. Damage is expected to depend upon the periodicity of the concrete structures compared to pipeline and valve structures and result in difficult-to-repair situations.

Water treatment plants close to the San Andreas fault, or those built in structurally poor foundation material, will experience differential settlement

which will require shutdown of the plants, damage assessment, and significant repair. Plant bypass, with emergency chlorination, will be crucial during the 72 hour period.

#### Waste Disposal

Many sewerage treatment facilities are located throughout the planning area, as evidenced by the locations shown on Map 1-W. Most of these systems involve gravity flow from the service area to the plant and discharge in an outfall to the Bay. Some systems involve pumping for all or part of their operation, a notable example being the "Super Sewer" of the East Bay Dischargers Authority which collects sewerage between San Leandro and Fremont (and from the Livermore Valley). Prolonged lack of electrical power for pumping and/or damage to system components at facilities along the Bay margin will necessitate sewerage discharge directly to the Bay.

Movement of liquids in tanks and other containers can damage baffles and other equipment. In areas of structurally poor ground, treatment plant structures may be on piling while pipelines are not. Differential response to shaking and consequent differential movements will cause damage where lines enter and leave structures. Various equipment -- tanks, panel boards, etc. -- that are poorly anchored will topple. For all of these various reasons, treatment plants are susceptible to significant damage, with the solution being to bypass the plant and discharge sewerage directly to the Bay.

The vast majority of the many treatment plants which service the Bay area are located adjacent to the Bay in structurally poor ground environments that

are highly susceptible to ground failure. In most cases, the contiguous trunk sewers and outfalls are similarly located. As shown on Map 1-W, these many plants have been categorically designated as "Damaged/Shutdown" based upon their location in areas of predicted intensity 8 (R-F) or greater and/or location within the area of high potential for ground failure as shown on Map 1-S. A few locations were marginal, in which cases, lacking the benefit of site-specific data, the author's judgment arbitrarily prevailed.

Waste water treatment plants have only limited storage available. If the treatment sequence cannot be reestablished before storage capacity is exceeded, the waste water will be discharged, with emergency chlorination, if possible, to reduce health hazards. In the Bay area, the discharge of raw sewerage can be expected to pollute most waterways, channels, harbors, and beaches, posing a serious public health hazard.

Algermissen and others (1972, pg. 186) concluded that two-thirds of the raw sewerage produced in San Francisco, San Mateo, and Santa Clara counties should be assumed to be discharged into the Bay.

Based upon the predicted intensities and the potential for ground failure that exists all around the Bay margins, we believe that this estimate could be extended to include an equivalent portion of the raw sewerage produced in the remaining areas that normally discharge to the Bay.

The major impact of the earthquake on the sewerage collection systems will come as a result of ruptured sewer mains. According to Algermissen and others (1972, p. 184), the "damage will be mainly a function of the soil conditions,

and the damage patterns will follow those of the water distribution systems.... During the wet season, landslides will substantially increase the sewer damage in localized hillside areas, but these are not expected to be major problems. Experience from landslides has shown that the sewer line breaks can be dug out and the sewerage allowed to flow in open cuts...if necessary. This raw sewerage may be a health hazard, but this should not be an insurmountable problem.

For planning purposes, the damage patterns previously given for water distribution systems also apply here, except that the outage time can be substantially less. From a practical standpoint, the sanitary sewer collection lines will not require significant use until the adjacent water distribution systems are restored."

The following (Algermissen and others, 1972, p. 183-4) relates to performance of sewers in San Francisco during the 1906 earthquake: "In the rocky portions of San Francisco the sewers were not affected. In portions where the rock was overlain with sand, there were no permanent displacements except where the original ground supported a fill; in such areas settlements occurred, and the sewers were destroyed. In filled-in tidal areas, marshlands and swamps, there was considerable movement in a number of places (the greatest near 16th Street and Valencia Street, where the settlement was 5 feet and lateral movement six feet) and in all such disturbed areas the sewers were destroyed (Transactions of the American Society of Civil Engineers, v. 59:214 [1907])."

## Planning Insights

The various water agencies need to develop and continue public information programs to acquaint their water users with the prospects of contamination and loss of water supply and how to mitigate these potential problems. Plans for firefighting need to be coordinated with water agencies and alternative sources of water planned for in critical areas. Additional interconnections between the major water delivery systems should be considered to provide valuable flexibility in regional water delivery operations, e.g., connections between the Hetch Hetchy Aqueduct and facilities of the East Bay Municipal Utility District and between the Hetch Hetchy Aqueduct and facilities of the Santa Clara Valley Water District.

## Recommended Further Work

Water agencies need to examine their transmission and distribution systems in detail to identify areas and facilities most likely to be impaired. Ongoing programs should be maintained to progressively upgrade facilities of questionable seismic resistance in areas of high vulnerability. Capabilities to provide emergency distribution of water using ground transportation needs to be evaluated in areas which are identified as having significant possibility of impaired water availability. Feasibility of providing additional interconnections between various transmission systems should be considered in order to provide alternative supply routes. A determination should be made of probable effects on the capability to deliver water to various portions of the Marin and San Francisco peninsulas assuming a prolonged lack of electrical

power for pumping. Fire fighting water requirements should be assessed in critical areas and estimates made of water supply impairment.

#### WATER SUPPLY AND WASTE DISPOSAL

##### MAP NOTATIONS

##### Map 1-W

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
W1	Lake Merced Pumping Station <u>Out of operation for more than 72 hours.</u> This pumping station is critical to the water distribution system of San Francisco as a booster to high-level reservoirs. It is vulnerable both because of its location within an area of expected high shaking intensity and because it is dependent on commercial electric power and lacks an auxiliary power supply.	San Francisco
W2	Broadmoor Pipelines <u>Out of operation for more than 72 hours.</u> These two principal pipelines supplying water to San Francisco are located on overpasses over Interstate 280 in the Broadmoor area.	San Mateo
W3	San Andreas Water Treatment Plant <u>Inoperable for more than 72 hours.</u> This plant is vulnerable because of its proximity to the surface rupture and its dependence on commercial electric power without an auxiliary power supply. The plant can be bypassed without significant impact to the water supply system.	San Mateo
W4	Hetch Hetchy Pipelines (North) <u>Out of service for several weeks.</u> Three major Hetch Hetchy pipelines, one cast iron, one riveted steel, and one welded steel, are all supported partly on shallow pilings, partly on	Santa Clara

a steel bridge, and partly embedded in Bay mud. For planning purposes, these are expected to fail either by differential responses of the various supports to earthquake vibrations or by ground failure due to liquefaction.

W5	Hetch Hetchy Pipelines (South)	Santa Clara
	<u>Open (Partial).</u>	
	Four Hetch Hetchy pipelines, three of steel and one of prestressed concrete, cross ravines on bridges in this area. Failure of one or more will occur at junctions of underground and elevated sections, but at least one will survive the earthquake.	
W6	City of Alameda	Alameda
	<u>Open (Partial).</u>	
	One or more of three cast iron pipelines that cross the estuary and supply the City of Alameda will be ruptured.	
W7	Penitencia Treatment Plant	Santa Clara
	<u>Closed for more than 72 hours.</u>	
	This water treatment plant and adjacent South Bay Aqueduct terminal facility will be inoperative for more than 72 hours because of seismically-triggered landslide displacements.	
W8	Hetch Hetchy Pipelines	Alameda
	<u>Open.</u>	
	One or more of four Hetch Hetchy pipelines will fail due to ground failure resulting from liquefaction.	
W9	Mokelumne Aqueduct	San Joaquin
	<u>Out of operation.</u>	
	This major facility will be damaged as a result of a levee failure in the Delta.	
W10	Bon Tempe Treatment Plant	Marin
	<u>Closed.</u>	
	The Bon Tempe treatment plant will be out of service because of landslide damage. In any case, the plant will be inoperative because of electrical power failure.	

W11 Southern Marin Pipeline Marin

Out of service.

This section of the Southern Marin Pipeline from Bon Tempe treatment plant will be ruptured due to slope failure.

W12 San Geronimo Treatment Plant and Booster Station Marin

Out of Service

This facility and ancillary transmission pipelines will be damaged by intense shaking in this alluvial valley near the surface rupture. Damage to pumping plants and/or the possible lack of electrical power for an extended period would limit water supply deliveries to the urban areas that must be pumped from storage reservoirs.

W13 North Bay Aqueduct Solano-Napa

Open

Facilities of the Putah South Canal and North Bay Aqueduct will be undamaged. Only minor damage will occur at the treatment plant in Jameson Canyon.

W14 Petaluma Aqueduct Sonoma-Marin

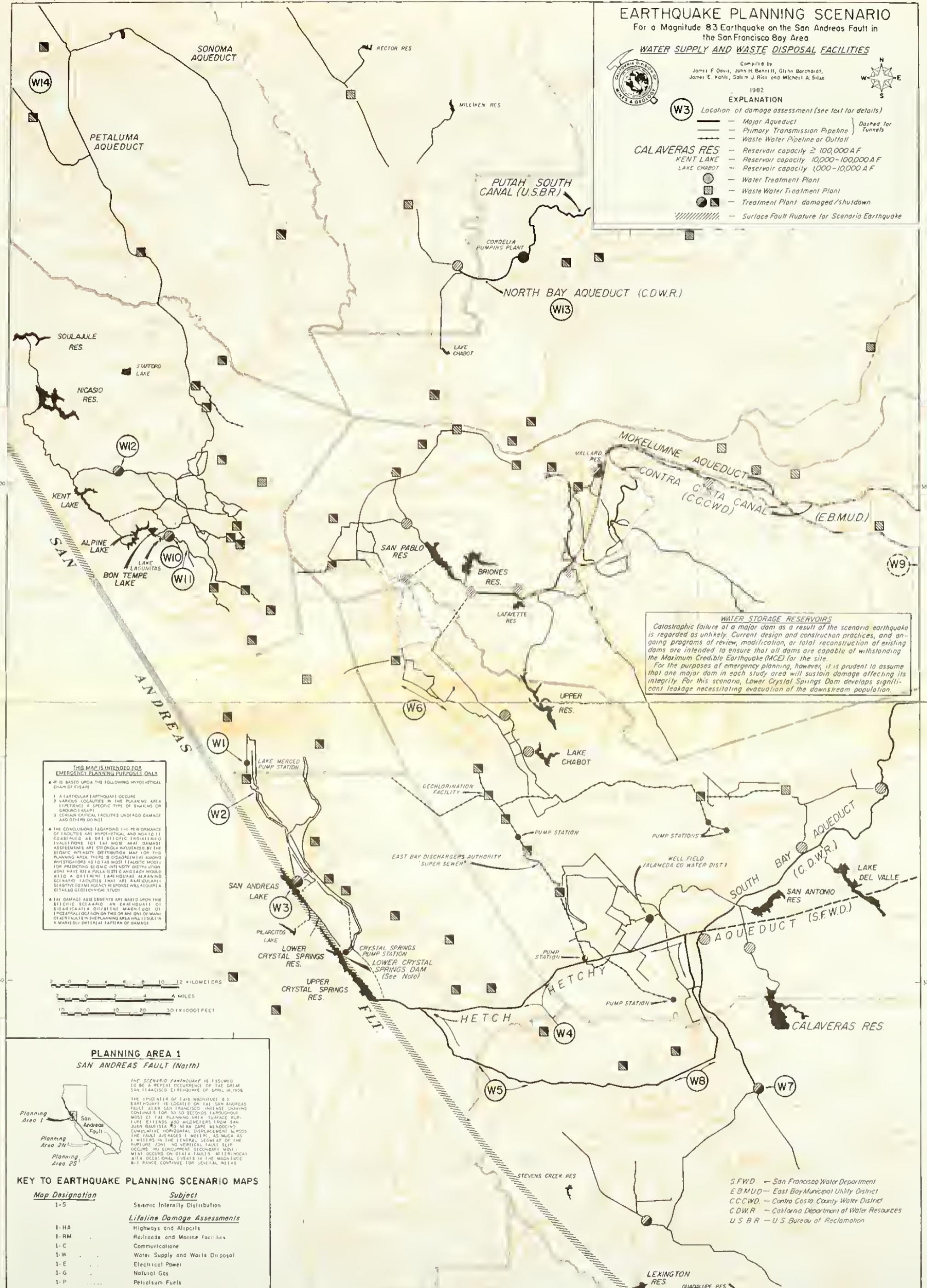
Out of Service

This facility is damaged by intense shaking and ground failure near Petaluma and Novato.

THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







EARTHQUAKE PLANNING SCENARIO: ELECTRICAL POWER

Map 1-E

General Pattern

The occurrence of the scenario earthquake will have a very significant impact on many of the major facilities that comprise the complex electrical power network serving this major urban area. (See Map 1-E.) Damage to power plants and their ancillary facilities within the planning area and in adjacent areas affected by the earthquake can be expected to result in a reduction in the combined generating capacity currently supplying the area with as much as 50 percent of its needs. The potential impact of this reduction in local output is lessened, however, by the availability of power from other sources outside the planning area and by the obvious significant reduction in consumer demand that will occur following the scenario earthquake. Immediate concerns will focus on repairs necessary to restore power within the damaged areas of greatest need. Major restoration problems include repairs necessary to route power through the major substations, restoration of damaged and collapsed transmission line towers, reactivation of equipment at local substations, and replacement of fallen poles, burned transformers, etc.

It is a reasonable judgment that, during some portion of the first 72-hour period following the earthquake, virtually all portions of the area will have experienced some loss of power, at least temporarily. Algermissen and others (1972) estimated that "It is reasonable for planning purposes to consider 50 per cent of the service connections in the study area to be without power

for 24 hours after a magnitude 8.3 shock.... in the congested portions of San Francisco and Oakland, the power outage should be considered at 100 percent for 24 hours, and thereafter at 75 percent for an additional 24 hours."

Electrical power facilities on the Marin and San Francisco peninsulas are particularly vulnerable to damage from the scenario earthquake, and the time that it will take to restore full power under the best of conditions could be prolonged. While the resources may be available to expeditiously deal with repairs to the system, the many complicating factors involved in attempting to conduct an extensive repair operation amidst the confusion and damage to such lifelines as communications and highways will create a substantial challenge. Realistically, power is unlikely to be restored to many areas for extended periods of time. Emergency planning for power-dependent systems such as communications, water supply, fire fighting, and waste treatment should be very cognizant of this possible eventuality.

#### Description

The principal distributor of electrical power throughout the San Francisco Bay planning area is the Pacific Gas and Electric Company (P.G.&E.). Major power facilities within the planning area include four major power plants (two in San Francisco and two in Contra Costa County at Antioch and Pittsburg), several smaller power plants, and an extensive network of major substations and interconnecting transmission lines that comprise the regional framework for the local distribution systems (see Map No. 1-E). Other major power facilities that contribute a large percentage of the Bay area electrical supply

are located outside the planning area, but within the region which will be significantly effected by the scenario earthquake. These include: (a) Moss Landing Power Plant on Monterey Bay, (b) the generating complex consisting of 15 relatively small power plants and related facilities at The Geysers Geothermal Area in Lake and Sonoma counties, and (c) transmission and switching facilities between these two power source areas and the planning area.

We have considered the likelihood of damage to the various power plants, certain major substations, and power transmission lines. We have indicated locations where, as a basis for emergency response planning, there is a reasonable expectation of damage. These assumptions are based predominantly on the regional patterns of intensities and areas of potential ground failure as shown on Map No. 1-S. No geologic site analysis or engineering evaluation of specific facilities was performed.

#### Power Plants

According to Algermissen and others (1973, pg. 274), "Experience indicates that well-designed electrical generating plants should suffer minimum (less than 5%) damage in intensity VIII (MM) zones and only slight (less than 10%) damage in intensity IX (MM) zones." They note that damage at the Valley Steam Plant during the 1971 San Fernando earthquake was negligible though estimated ground motion of this plant was intensity VIII (MM). Plants, auxiliary switchyards, and other ancillary facilities located in areas of high ground water and/or poor soil conditions (such as Bay mud), however, are susceptible to significant damage as a result of ground failure.

The capacity of the major power generating facilities affected by this earthquake, aggregating about 7100 MW, is principally derived from the Moss Landing Power Plant, the four major plants in the Bay area, and those at The Geysers. Given the assumptions set forth in the damage assessments that follow, it is possible that only about half of this generating capacity may be available for some extended period following the scenario earthquake. This conclusion is based upon the possibility of damage to transmission lines as well as damage to the affected plants and their related facilities.

While the impact of this potential loss of generating capacity is significant, the net impact upon the heavily damaged metropolitan service area can be ameliorated. Because P.G.&E. has access to other sources of power from outside the affected area, it may be possible to reroute power to some consumers. The routine consumer needs for power will be far less than normal while both power generation and consumer facilities are being gradually restored. For planning purposes, all emergency operations and support systems necessary for responding to the scenario earthquake should have alternate power supply sources.

#### Major Substations

Transformer substations are essential to transmission both of locally generated power and of power available from outside the region affected by the earthquake. These substations, which contain banks of switches, circuit breakers, and massive transformers, are particularly vulnerable to damage by earthquake shaking.

On Map No. 1-E, several major substations are designated by a symbol indicating "significant damage at some, not all, locations." These substations are categorically considered because of their location within or very near areas of predicted intensity 9 (R-F), as shown on the Seismic Intensity Distribution Map (Map No. 1-S). Based upon this intensity pattern, it is a reasonable expectation that each of these stations will sustain some damage. In the absence of site-specific engineering and geologic evaluations, it is prudent for emergency planning purposes to conclude that damage is likely to occur at some substations sufficient to impair or curtail their performance seriously. The performance of these facilities should be further considered by emergency planners with the benefit of site-specific advice from the utility. Thus, while total failure is unlikely, parts of many substations will be damaged, and some of these will be incapacitated. In coping with such circumstances, it should be noted that the utility has considerable flexibility with regard to routing power flow and, therefore, temporary reassignments may be possible.

For planning purposes, it should be assumed that substations on the San Francisco peninsula, including the important Martin substation (see note E-8), will be heavily damaged. The Ignacio substation, which serves most of Marin County, should also be assumed to be heavily damaged (see note E-9). Such affects upon these critical facilities will further impair transmission of power to San Francisco and to Marin County until repairs are made. For planning purposes, temporary repairs could permit transmission of some power within 12 hours or so (provided transmission lines are all intact), but complete repairs to these substations would involve a more extended repair period -- possibly beyond 72 hours.

The conclusions of this investigation regarding the substations are in general agreement with those presented in the NOAA report. "Despite their good anchorages to power poles, to rails, and the like, many hundreds of transformers will be knocked out, and some will burn as they have in other earthquakes. Switchgear damage will result in serious power outages. Failure of porcelain insulators will additionally result in significant numbers of power failures" (Algermissen and others, 1972, p. 182).

#### Transmission Lines

Transmission towers and lines are principally subject to damage through secondary effects such as landslides. Conductor lines swinging together will only cause interruptions for a few seconds.

Within the planning area, numerous major transmission routes traverse extensive areas subject to intense shaking and/or ground failure. Major 230 KV transmission lines serving the San Francisco peninsula are routed across and around the perimeter of the south Bay and along the west Bay margin to San Francisco. Similar high-voltage lines serving Marin County traverse southern Napa and Sonoma counties. Lengthy segments of these facilities are located in Bay mud subject to ground failure. Many other major transmission lines, located along and across the surface rupture of the San Andreas fault in San Mateo, Santa Clara, Santa Cruz, and Marin counties, are vulnerable to intense shaking, surface fault rupture, and landsliding.

In view of the fact that numerous major routes are exposed to these hazards over extensive distances, it is a reasonable expectation that some of these major lines will be out of service because of damaged and collapsed towers. While the loss of a few towers would not pose a formidable situation, damage could be widespread and significantly compounded by landslides during a wet winter season or by fire caused by fallen lines during the dry season.

While transmission lines in the East Bay area are also exposed to landsliding and other ground failures, the degree of probable damage appears far less than in the areas on the west side of the Bay discussed above.

#### Summary

Algermissen and others (1972, pg. 182) concluded that "It is reasonable for planning purposes to consider 50% of the service connections in the study area to be without power for 24 hours after a magnitude 8.3 shock.... In the congested portions of San Francisco and Oakland, the power outage should be considered at 100% for 24 hours, and thereafter at 75% for an additional 24 hours.... For scenario purposes, an 8.3 magnitude earthquake on the San Andreas fault will require the use of all standby power facilities throughout San Francisco, San Mateo, and Santa Clara counties, and 50% of standby power facilities in Marin, Contra Costa, and Alameda counties." In the event of major damage to the Ygnacio substaion near Novato, compounded by possible damage to transmission lines in this area, as assumed in this scenario, Marin County will also be highly dependent upon standby power facilities.

Recovery time for transmission of electrical power will be different from place to place in the Bay area, but San Francisco, Marin, and San Mateo counties can be expected to be without power for the most lengthy period because of the more vulnerable nature of the corridor through which power is routed to these areas. Steinhardt (1978) points out that "in a great earthquake, a large number of users will be without power, temporarily at least, and that.... It is reasonable to expect that the rate of service restoration will exceed the rate of recovery of customer demand." On the other hand, it is the judgment of Algermissen and others (1972, p. 182-183) that "the repair of the very extensive damage will require logistic support which, in our opinion, will require many days to restore even all vital services. It must be remembered that blocked streets and roads, higher priority medical requirements, and aftershocks preclude any perfect response effort to the power outages to be expected. The unexpected can and does happen as it did in the power blackouts a few years ago in the northeastern states."

IT IS ASSUMED IN THIS 1982 SCENARIO THAT ALL CRITICAL FACILITIES SUCH AS HOSPITALS, FIRE AND POLICE STATIONS, EMERGENCY COMMUNICATIONS AND OPERATION CENTERS, AND WATER PUMPING STATIONS WILL REQUIRE STANDBY GENERATING EQUIPMENT AND EMERGENCY FUEL SUPPLIES IN SAN FRANCISCO, SAN MATEO, SANTA CLARA, AND MARIN COUNTIES.

#### Planning Insights

Society has evolved to where it is highly dependent upon a continuous supply of electrical power to meet a myriad of everyday needs. Indeed, the

human environment within modern high-rise structures is entirely controlled by it. Consequently, everyone, particularly those entities responsible for maintenance of lifelines and critical facilities, should examine their ability to function in the event of a prolonged absence of electrical power.

At the individual citizen level, the following is very appropriate. Commenting upon the lack of electrical power in Santa Cruz County that resulted from landsliding during the intense storm of January 4, 1982, Stegner (1982) concluded: "It may be a long time before we need to dig out our old boy scout manuals again, but, while we sit around waiting for the killer earthquake that everybody seems to regard as inevitable, we might take a lesson from the killer storm that nobody expected. The difference between misery and comfort, relatively speaking, may be no more than a can of kerosene and a can of gasoline in the garage, a can of soup in the larder, and a half dozen flashlight batteries in the kitchen drawer. What was the motto? Be prepared?" An intensive public education program to condition people to expect power outages after the earthquake is clearly appropriate.

#### Recommended Further Work

The critical power corridors and facilities should be examined in light of the best geologic data available to assess the vulnerability of specific elements in the electrical power network. Capability to respond and accomplish timely repairs to a widespread affected area as described in this scenario needs to be evaluated further. Probable interruptions of other lifelines that are discussed in this report, especially water supply, waste treatment, and

communications, must be taken into account in planning an earthquake-emergency response for this utility. Strategies for repair of facilities must take into account the post-earthquake feasibility of ground and other means of transportation. Strategies for rerouting power into the area to augment decreased capacity within the region should also be emphasized. Public education should be undertaken to contend with the power outages.

#### ELECTRICAL POWER

##### MAP NOTATIONS

(See Map 1-E.)

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
E1	<u>Moss Landing Power Plant</u>	Monterey
	Moss Landing Power Plant (capacity 2060 MW) is located on Monterey Bay, some 18 km west of and near the southern limit of surface rupture on the San Andreas fault, as assumed in this scenario. This area suffered extensive ground failure due to liquefaction during the 1906 earthquake (Youd and Hoose, 1978). Although the power plant is located on bedrock (Hoose, 1982, personal communication) and, presumably, susceptible only to damage by shaking, the auxiliary switchyards, fuel handling and storage facilities, and nearby transmission towers are assumed to be vulnerable to damage by ground failure as well as shaking. In addition, major power transmission routes from Moss Landing to the San Francisco Bay area must cross both the surface rupture and the Santa Cruz Mountains in steep terrain subject to landslides and consequent tower damage. Considering these various possibilities, we have assumed that power from Moss Landing will be unavailable for at least the 72-hour post-earthquake period. Algermissen and others (1972, pg. 182) concluded previously that "Sufficient damage will occur to power generating facilities on the San Francisco and Moss Landing sites to require shut-down."	

E2 Potrero and Hunters Point Power Plants San Francisco  
Shutdown of the Potrero and Hunters Point Power Plants (combined capacity, 896 MW), located near the Bay margin and subjected to intense shaking

and ground failure, is a reasonable expectation for planning purposes. Algermissen and others (1972, pg. 182) also assumed that these two plants would be shutdown as a result of a similar M 8+ scenario earthquake.

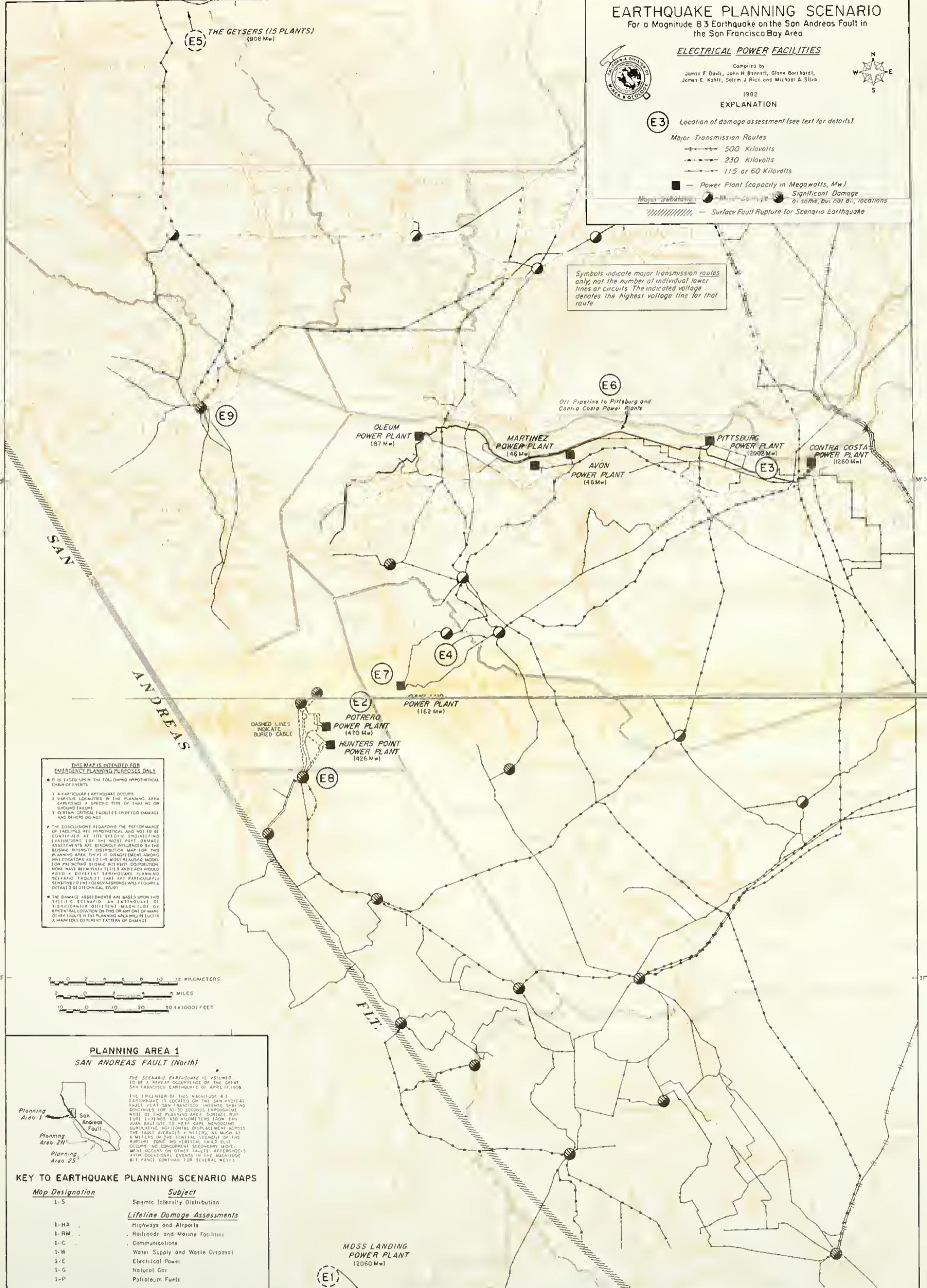
- E3 Pittsburg and Contra Costa Power Plants Contra Costa  
Algermissen and others (1972, pg. 182) concluded that these plants would remain operational. Though the prospects of significant damage to these plants is probably remote, both the plants and their related facilities are located on or near Bay Mud, which may be subject to ground failure. For planning purposes, therefore, we have assumed that sufficient damage will occur to plant facilities to reduce the combined power output of the two plants by 15 percent.
- E4 Moraga Transmission Line Contra Costa  
This power transmission line to the East Bay crosses a large landslide immediately west of the Moraga substation, and while the substation will survive both the shaking and a reactivation of the landslide, the transmission line will not.
- E5 The Geysers Geothermal Area Sonoma-Lake  
Currently, some fifteen power plants in The Geysers Geothermal Area have a total generating capacity of about 900 MW. Turbines are driven by steam piped to the plants from some 200 wells. Located some 50 km east of the San Andreas fault, earthquake intensity at The Geysers will be 7 (R-F) or less. The earthquake will, however, have a significant impact upon the generating capacity of the area as a result of landslides on steep unstable slopes, a problem compounded during the wet winter season. Landslides could cause serious damage to any one or all power-related facilities in The Geysers, i.e. certain of the older power plants, the steam producing wells, the extensive above-ground steam piping, and power transmission lines routed across steep mountainous terrain. In addition to these, the road system within The Geysers area is also extremely vulnerable to landslides, a factor which could cause a major impediment to timely repairs. For planning purposes, we have assumed that production of electrical power in The Geysers area is diminished by one-third as a result of this scenario earthquake.
- E6 Power Plant Fuel Line Contra Costa  
The oil supply pipeline between Richmond and the Pittsburg and Contra Costa power plants crosses areas susceptible to ground failure by liquefaction; but no damage to this line is forecast. In any event, repairs could be accomplished rapidly. The availability of electrical power for pumping and the integrity of pumping equipment may be a more critical consideration.

- E7 Oakland Power Plant Alameda  
This relatively small plant is susceptible to intense shaking and ground failure. We have, for planning purposes, concluded that this plant will be shutdown for at least 72 hours.
- E8 Martin Substation San Mateo  
This substation is located in an area of predicted intense shaking and possible ground failure, and major damage to some equipment at this station is a reasonable expectation. Routing of power through this critical station constitutes a major consideration in the planning for restoration of power to the City.
- E9 Ygnacio Substation Marin  
This critical substation handles all power routed south into Marin County. Prudent planning should allow that this facility, founded on shallow Bay mud, could be seriously damaged by shaking and/or ground failure.

THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







EARTHQUAKE PLANNING SCENARIO: NATURAL GAS

Map 1-G

General Pattern

Damage to natural gas facilities will consist primarily of (a) some isolated breaks in the major transmission lines and (b) innumerable breaks in mains and individual service connections within the distribution systems, particularly in the areas of intense shaking and/or poor ground nearer the Bay margins. For planning purposes, it should be considered that these many leaks in the distribution system will affect a major portion of the urban areas in the East Bay, the South Bay, and the San Francisco and Marin peninsulas resulting in a loss of service for extended periods. Sporadically distributed fires should be expected at the sites of a small percentage of ruptures both in the transmission lines and the distribution system.

Transmission pipelines serving the San Francisco Peninsula are most vulnerable to damage. Damage and repair problems to major transmission lines in the East Bay should not be significant. No significant damage to transmission facilities in the North Bay is envisioned.

Description

Natural gas is supplied to the region through facilities of the Pacific Gas and Electric Company (P.G.&E.). The major gas transmission lines that

serve the San Francisco Bay area are shown on Map 1-G. Locations of the several gas storage holders and terminals are also indicated.

Damage to the gas transmission lines and related facilities will be concentrated in the areas of poor ground around the Bay margin. Some pipeline damage will occur as a result of fault rupture on the Peninsula and as a result of seismically-triggered landslides near Upper Crystal Springs Reservoir and in the hills east of Fremont.

The low pressure gas storage facilities (holders) have numerous seals and are expected to develop leaks as a result of shaking. The holders, which are not particularly crucial to the supply system, can be bypassed, and the gas transmission systems will still be operational provided the transmission mains have not been ruptured.

Many gas leaks will occur within the distribution mains and individual service connections, particularly in the areas that experience ground failure due to settlement, liquefaction, or seismically-triggered landslides. It can be expected that natural gas will be unavailable to all or parts of most urban areas in the East Bay, South Bay, and San Francisco Peninsula for an extended period of time. "An important consideration with gas is that the complete loss of supply to a large number of customers is a serious matter in itself. Unlike electricity, which can usually be turned off and on at will, the restoration of gas service is an expensive and time-consuming task. If a pipe-line is broken, or part of a distribution network loses all pressure, every customer being supplied from that network must individually be shut down before repressuring can begin. To prevent explosions, the entire system of

mains, feeders, and service lines in the affected area must be purged before pilot lights can be relighted and service restored. In addition, extensive gas leak detection surveys may be needed, using flame ionization equipment throughout the affected area" (California Public Utilities Commission, LNG Task Force, 1980).

Algermissen and others (1972) concluded earlier that "An 8.3 magnitude shock on the San Andreas fault probably will not cause excessive damage to the natural gas system, although localized outages will require extensive repair periods.... However, the transmission lines do pass through potentially unstable ground regions along San Francisco Bay."

#### Planning Insights

The various major utilities should collaborate in continuing public education programs to explain the probable consequence of a major earthquake on their service capabilities and what actions should be taken by the public to mitigate the effects.

#### Recommended Further Work

In areas of poor ground where potential for major pipeline failures exist, alternative line(s) in stable materials should be considered. The adequacy and location of automatic pressure-activated shut-off valves should be periodically reviewed in the light of new geologic information concerning potential problem areas.

Locations where gas availability would be most severely impacted should be identified. Emergency users of natural gas should be identified. The likelihood of fire due to breaks in local gas mains should also be investigated.

NATURAL GAS

MAP NOTATIONS

(See Map 1-G)

<u>NO.</u>	<u>LOCATION</u>	<u>COUNTY</u>
G1	Richmond	Contra Costa
	Pipeline rupture will occur due to ground failure.	
G2	SFO Pipeline	San Mateo
	Rupture of old pipeline sections will occur due to ground failure caused by liquefaction. "For planning purposes, the transmission line skirting the west side of the Bay is estimated to be out of service due to ground failure" (Algermissen and others, 1972, p. 180).	
G3	San Andreas Fault	San Mateo
	Rupture of pipelines will occur due to ground breakage along the San Andreas fault zone between San Andreas Lake and Route 1. Water pipelines ruptured and telescoped at this location during the 1906 event (Harry Tracy, San Francisco Water Department, oral communication, 1982). Pipeline rupture will also occur near Upper Crystal Springs Reservoir (between San Mateo Creek and 4 kilometers southeast of the junction of Interstate 280 and Route 92) due to landslides.	
G4	Coyote Creek	Alameda-Santa Clara
	The terminal will be damaged and pipelines will rupture due to ground failure caused by widespread liquefaction.	

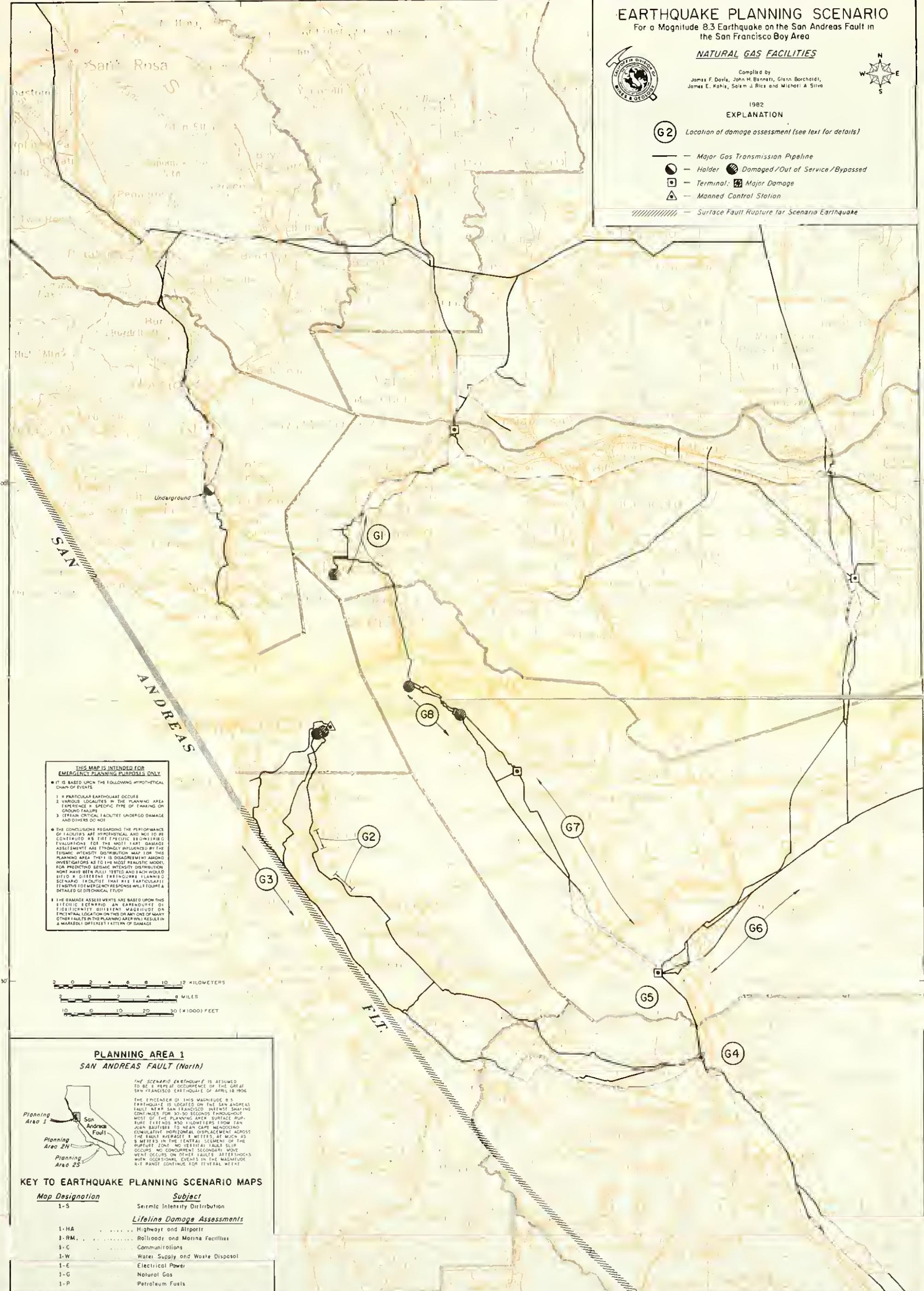
- G5 Newark Alameda  
Ground failure will affect pipelines and there will be some damage to the terminal.
- G6 Sunol Area Alameda  
One or more pipeline ruptures will occur due to landslides triggered by the earthquake.
- G7 Oakland to San Jose Alameda  
The pipeline will be ruptured along this route due to ground failure caused by liquefaction.
- G8 Oakland Waterfront Alameda  
Pipeline rupture will occur due to ground failure caused by liquefaction.



THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







## EARTHQUAKE PLANNING SCENARIO: PETROLEUM FUELS

### Map 1-P

#### General Pattern

Following the scenario earthquake, operations at the several major refineries in the Bay area will be curtailed until all facilities are thoroughly inspected and repairs accomplished. Pipelines are expected to withstand the shaking without significant impairment, but ruptures can be expected wherever contrasting support conditions are modified by differential movements and ground failure occurs due to liquefaction or seismically-triggered landslides. Large storage tanks and marine loading facilities located on potentially responsive foundation materials are also subject to damage.

#### Description

Important petroleum-related facilities that could sustain significant damage as a result of the scenario earthquake include (a) the several major refineries located on San Pablo Bay and east of the Carquinez Straits, (b) several critical petroleum product pipelines connecting these refineries to distribution terminals near San Francisco and Oakland International Airports and in San Jose, and (c) Bayside oil-handling facilities for marine (tanker) transport.

Refineries are extremely complex facilities, and the prediction of their behavior during the earthquake is beyond the scope of this study. Refining

and/or storage facilities at each of the major refineries (see Map No. 1-P) are located upon or in proximity to the estuarine Bay mud and marsh deposits that are most susceptible to ground motion amplification and liquefaction with possible ground failure. Site-specific studies will be required to determine the extent of vulnerability to each facility's refining and storage capability.

The several major petroleum product pipelines that serve the metropolitan area cross extensive areas of structurally poor ground near the Bay margin. Ground failures resulting in distinct differential movements could cause pipe rupture in these areas. Pipe connections at the terminal facilities are also vulnerable due to the differing response between buried pipe and rigid structures.

Algermissen and others (1972, p. 186) pointed out that "There are other complicating factors related to petroleum pipelines. In so far as it is known, none of these pipelines have automatic shut-off valves. If the rupture occurs during the height of the dry season in the Berkeley Hills and other surrounding areas, fire could be a very serious problem. This could also be widespread during the rainy season, should the petroleum ignite as it is washed downstream rapidly with storm waters into the sewers."

Shut-off valves are installed on many of these pipelines, and will automatically function when the line pressure drops below a particular threshold, such as would occur in the case of a pipe rupture. These valves are commonly dependent upon electrical power, however, so in the event of a major earthquake and possible large-scale power loss, these valves would not perform.

Those refineries having marine terminals can anticipate some damage to these facilities as a result of intensity 8-9 (R-F) shaking and high potential for ground failure common to all Bayside refinery locations.

#### Planning Insights

Plans should be developed to ensure distribution of fuel to those locations designated for emergency response operations, including airports. Appropriate facilities, including emergency power and pumping capability, should be available at fuel storage locations for refueling of helicopters and other emergency vehicles. Major damage to the trans-Bay product lines could seriously impact fuel availability on the San Francisco peninsula.

#### Recommended Further Work

All petroleum product pipelines serving the metropolitan areas should be examined in detail relative to their exposure to ground failure. The adequacy and locations of automatic shut-off valves should be examined on all product lines and remedial measures undertaken, as appropriate, to ensure a functional system. Locations of fuel storage facilities, including those for aviation fuels, should be predetermined and emergency procedures established to ensure that these supplies will be available when needed. An inventory of fuel storage facilities throughout the area would facilitate planning of emergency response efforts that will be dependent upon nearby sources of fuel.

The need for fire fighting emergency plans to cope with pipeline ruptures should be considered -- particularly for areas where the pipelines are considered to be most vulnerable to this effect.

PETROLEUM FUELS

MAP NOTATIONS

(See Map 1-P)

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
P1	Terminal Facilities in the Richmond Area	Contra Costa
	Poor ground conditions and differential movements at the junctures of pipelines and terminal facilities will result in moderate damage.	
P2	Coyote Creek	Alameda-Santa Clara
	The area near the mouth of Coyote Creek suffered extensive ground failure due to liquefaction during the 1906 earthquake (Youd and Hoose, 1978). Pipelines are subject to failure due to lateral spreading caused by liquefaction.	
P3	Oakland to San Jose	Alameda
	Pipeline failure will occur along this route due to ground failure.	
P4	Alameda - Bay Crossing	Alameda
	Differential movement will produce damage where the pipelines enter the Bay, but the Bay crossings themselves will survive.	
P5	Albany to Oakland	Alameda
	Pipeline rupture will occur along this route due to ground failure.	
P6	Richmond - Crockett	Contra Costa
	Pipeline damage will occur due to ground failure.	

- P7 Mormon Temple Landslide Alameda  
Pipeline rupture due to landslide movement.  
A reactivation of this landslide within the Hayward fault zone has previously caused pipeline rupture at this location.
- P8 Fuel Terminals - Vicinity Oakland International Airport Alameda  
Ground failure or differential movement of structures will rupture pipelines at the junctions with terminals.
- P9 Martinez Contra Costa  
Ground failure will cause numerous pipeline ruptures in this area of many pipeline facilities.
- P10 Sunol Area Alameda  
Pipeline rupture will occur due to a seismically-triggered landslide.
- P11 Suisun Marsh Solano  
Pipeline rupture will occur due to settlement or lateral spreading caused by liquefaction similar to that produced here in the 1906 earthquake.
- P12 Honker Bay Solano  
Pipeline rupture will occur due to settlement or lateral spreading caused by liquefaction similar to that produced here in the 1906 earthquake.



THIS MAP IS INTENDED FOR  
EMERGENCY PLANNING PURPOSES ONLY

- IT IS BASED UPON THE FOLLOWING HYPOTHETICAL CHAIN OF EVENTS:
  1. A PARTICULAR EARTHQUAKE OCCURS
  2. VARIOUS LOCALITIES IN THE PLANNING AREA EXPERIENCE A SPECIFIC TYPE OF SHAKING OR GROUND FAILURE
  3. CERTAIN CRITICAL FACILITIES UNDERGO DAMAGE AND OTHERS DO NOT
- THE CONCLUSIONS REGARDING THE PERFORMANCE OF FACILITIES ARE HYPOTHETICAL AND NOT TO BE CONSTRUED AS SITE-SPECIFIC ENGINEERING EVALUATIONS. FOR THE MOST PART, DAMAGE ASSESSMENTS ARE STRONGLY INFLUENCED BY THE SEISMIC INTENSITY DISTRIBUTION MAP FOR THIS PLANNING AREA. THERE IS DISAGREEMENT AMONG INVESTIGATORS AS TO THE MOST REALISTIC MODEL FOR PREDICTING SEISMIC INTENSITY DISTRIBUTION. NONE HAVE BEEN FULLY TESTED AND EACH WOULD YIELD A DIFFERENT EARTHQUAKE PLANNING SCENARIO. FACILITIES THAT ARE PARTICULARLY SENSITIVE TO EMERGENCY RESPONSE WILL REQUIRE A DETAILED GEOTECHNICAL STUDY.
- THE DAMAGE ASSESSMENTS ARE BASED UPON THIS SPECIFIC SCENARIO. AN EARTHQUAKE OF SIGNIFICANTLY DIFFERENT MAGNITUDE ON THIS OR ANY ONE OF MANY OTHER FAULTS IN THE PLANNING AREA WILL RESULT IN A MARKEDLY DIFFERENT PATTERN OF DAMAGE.







## GLOSSARY

(Definitions adapted from Glossary of Geology, American Geological Institute, 1981, and American Heritage Dictionary, 1981).

ALLUVIUM	Surficial sediments consisting of poorly consolidated gravels, sands, silts, and clays deposited by flowing water.
BEDROCK	A general term for coherent, usually solid rock, that underlies soil or other unconsolidated surficial material.
DEFORMATION	A general term for the process of folding, faulting, shearing, compression, or extension of rocks.
EARTHQUAKE	Vibratory motion propagating within earth or along its surface caused by the abrupt release of strain (elastically deformed rock) by displacement movement along a fault surface.
EARTHQUAKE INTENSITY	A measure of the effects of an earthquake at a particular place. Intensity depends upon the earthquake magnitude, distance from epicenter, and upon the local geology.
EARTHQUAKE MAGNITUDE	A measure of the size of an earthquake, as determined by measurements from seismographic records.
FAULT	A fracture (rupture) or a zone of fractures along which there has been displacement of adjacent earth material.
GROUND FAILURE	Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.
GROUND RUPTURE	Displacement of the earth's surface as a result of fault movement associated with an earthquake.
ISOSEISMAL AREA	An area composed of points of equal earthquake intensity on the earth's surface.
LIFELINES	Facilities such as highways, bridges, tunnels, major airports, electrical power lines, fuel pipelines, communication lines, water supply lines, marine terminals and railroads.
LIQUEFACTION	The transitory transformation of sandy water-saturated alluvium with properties of a solid into a state possessing properties of a liquid as a result of earthquake shaking.

MAGNITUDE	See Earthquake Magnitude.
MODIFIED MERCALLI SCALE	See Appendix.
REINFORCED MASONRY	Masonry construction with steel reinforcement.
RICHTER SCALE	See Appendix.
ROSSI-FOREL SCALE	See Appendix.
SEISMIC HAZARD	A condition of risk or potential damage due to an earthquake.
THRUST FAULT	A fault with a dip of 45° or less over much of its extent, on which the hanging wall appears to have moved upward relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.
WATER TABLE	The upper surface of ground water saturation of pores and fractures in rock or surficial earth materials.

## REFERENCES

- Algermissen, S.T., Rinehart, W.A., Dewey, James, Steinbrugge, K.V., Lagorio, H.J., Degenkolb, H.J., Cluff, L.S., McClure, F.E., Scott, Stanley, and Gordon, R.F., 1972, A study of earthquake losses in the San Francisco Bay area: Data and analysis: National Oceanic and Atmospheric Administration report prepared for the Office of Emergency Preparedness, 220 p.
- Algermissen, S.T., Hopper, Margaret, Campbell, Kenneth, Rinehart, W.A., Perkins, David, Steinbrugge, K.V., Lagorio, H.J., Moran, D.F., Cluff, L.S., Degenkolb, H.J., Duke, C.M., Gates, G.O., Jacobsin, D.W., Olsen, R.A. and Allen, C.R., 1973, A Study of earthquake losses in the Los Angeles, California area; data and analysis: National Oceanic and Atmospheric Administration report prepared for the Federal Disaster Assistance Administration, 331 p.
- Barosh, P.J., 1969, Use of seismic intensity data to predict the effects of earthquakes and underground nuclear explosions in various geologic settings: U.S. Geological Survey Bulletin 1279, 93pp.
- Bishop, C.C., Knox, R.D., Chapman, R.H., Rodgers, D.A., and Chase, G.B., 1973, Geological and geophysical investigations for Tri-cities seismic safety and environmental resource study: California Division of Mines and Geology Preliminary Report 19, 44 p.
- Blake, M.C., Jr., Bartow, J.A., Frizzell, V.A., Jr., Schlocker, J., Sorg, D., Wentworth, C.M., and Wright, R.H., 1974, Preliminary geologic map of Marin and San Francisco counties and parts of Alameda, Contra Costa and Sonoma counties, California: U.S. Geological Survey Basic Data Contribution 64 (Miscellaneous Field Studies Map MF-574).
- Borcherdt, R.D., Gibbs, J.F., and Lajoie, K.R., 1975, Prediction of maximum earthquake intensity in the San Francisco Bay region, California, for large earthquakes on the San Andreas and Hayward Faults: U.S. Geological Survey Field Studies Map MF-709.
- California Department of Water Resources, 1981, Maps showing water table elevations in parts of northern San Francisco Bay.
- Castenada, Joan, 1981, Letter to James F. Davis, State Geologist, December 2, 1981, from the Airport Director, Hayward Air Terminal, concerning a preliminary version of the Earthquake Planning Scenario for highways and airports. Includes interoffice report of 9/18/81 concerning pavement load capacities.
- CDOT (California Department of Transportation), 1981, Scenario of effects on state transportation for an 8.3 earthquake along the northern San Andreas fault. Written communication from CALTRANS to the State Geologist, Sept. 1, 1981, 13 p.
- Contra Costa County Planning Department, 1974, Technical report for the seismic safety element (draft): A report of the Contra Costa land use and transportation study, 263 p.

County of Santa Clara Planning Department, 1976, Seismic safety plan: An element of the general plan, Santa Clara County. 119 p.

Dehaesus, A.A., and Nelson, Todd, 1981, Letter to James F. Davis, State Geologist, November 9, 1981, from the Director of Planning and the Senior Planning Geologist, Contra Costa County Planning Department concerning their review of a preliminary version of the Earthquake Planning Scenario for highways and airports.

Eggleston, Buzz, 1980, Peninsula overpasses that pose quake risk: Times Tribune Weekly (North), Wednesday, November 19, 1980.

Evernden, J.F., Hibbard, R.R., and Schneider, J.F., 1973, Interpretation of seismic intensity data: Seismological Society of America Bulletin, v. 63, p. 399-422.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminous United States--Their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 50 p.

Finlayson, D.J., 1982, Emergency response for plan annex - water and waste disposal systems, Draft report for Governor's Emergency Task Force on Earthquake Preparedness, dated January 26, 1982.

Helley, E.J., Lajoie, K.R., and Burke, D.B., 1972, Geologic map of late Cenozoic deposits, Alameda County, California: U.S. Geological Survey Basic Data Contribution 48.

Jacobs, A.B., 1974, Community safety plan: A proposal for citizen review: San Francisco Department of City Planning, 68 p.

Laird, R.T., and others, 1979, Quantitative land-capability analysis: U.S. Geological Survey Professional Paper 945, 115 p.

Lajoie, K.R., Helley, E.J., Nichols, D.R., and Burke, D.B., 1974, Geologic map of unconsolidated and moderately consolidated deposits of San Mateo County, California: U.S. Geological Survey Basic Data Contribution 68 (Miscellaneous Field Studies Map MF-575).

Lanferman, P.E., and Danehy, E.A., 1981, Letter to James F. Davis, State Geologist, November 12, 1981, from the Engineer-Manager and the Engineering Geologist, Public Works Agency, County of Alameda, concerning a preliminary version of the Earthquake Planning Scenario for highways and airports.

Lawson, A.C., and others, 1908, The California earthquake of April 18, 1906, Report of the State Earthquake Commission (2 v. and atlas): Carnegie Institution of Washington, Washington, D.C.

LNG Task Force, 1980, Recommendations for an earthquake hazards reduction program. Report prepared for the California Seismic Safety Commission by the California Public Utilities Commission, San Francisco, California.

Louis, E.B., 1981, Letter to Jack Bennett, C.D.M.G., December 4, 1981, from the Principal Civil Engineer, Public Works, Department of Private Development, City of San Jose, concerning the comments made by Ron Mearns, the City Engineering Geologist, on a preliminary version of the Earthquake Planning Scenario.

Lunn, David, 1982, Areas of high ground water (less than 30 feet) in the Livermore Valley: Written communication, Alameda County Flood Control and Water Conservation District, Zone 7.

McCarty, J.R., 1981, Letter to James F. Davis, State Geologist, November 12, 1981, from the Director of Public Works, City of Oakland, concerning a preliminary version of the Earthquake Planning Scenario.

Nason, Robert, 1980a, Damage in San Mateo County, California in the earthquake of 18 April 1906: U.S. Geological Survey Open-File Report 80-176, 49 p.

Nason, Robert, 1980b, Damage in Santa Clara and Santa Cruz counties, California caused by the earthquake of 18 April 1906. U.S. Geological Survey Open-File Report 80-1076, 63 p.

Nason, Robert, 1982, Damage in Alameda and Contra Costa counties, California, in the earthquake of 18 April 1906: U.S. Geological Survey Open-File Report 82-63, 41 p.

Nichols, D.R., and Wright, N.A., 1971, Preliminary map of historic margins of marshland, San Francisco Bay, California: U.S. Geological Survey Basic Data Contribution 9.

Perkins, Jeanne, and others, 1981, A guide to ABAG's earthquake hazard mapping capability: Association of Bay Area Governments, Berkeley, California.

Rice, S.J., 1973, Geology and geologic hazards of the Novato area, Marin County, California: California Division of Mines and Geology Preliminary Report 21, 47 p.

Rice, S.J., 1975, Geology for planning: Novato area, Marin County, California: California Division of Mines and Geology, unpublished report, 57 p.

Rice, S.J., Smith, T.C., and Strand, R.G., 1976, Geology for planning: Central and southeastern Marin County, California: California Division of Mines and Geology Open-File Report 76-2 SF, 103 p.

Sedway/Cooke, 1977, Health and safety element: Seismic safety, safety, noise. A part of the Solano County general plan, 78 p.

Sims, J.D., Fox, K.F., Jr., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of Solano County and parts of Napa, Contra Costa, Marin and Yolo counties, California: U.S. Geological Survey Basic Data Contribution 54 (Miscellaneous Field Studies Map MP-484).

Snyder, W.G., 1981, Letter to James F. Davis of CDMG, November 30, 1981, from the Manager of Design, Bay Area Rapid Transit District concerning a preliminary version of the Earthquake Planning Scenario for railroads.

Stegner, P., 1982, Rained Out, California Magazine, March, 1982.

Steinhardt, O.W., 1978, Protecting a power lifeline against earthquakes: Journal of Technical Councils, ASCE, v. 104, n. TC1, Proceedings Paper 14115, November 1978, p. 49-57.

Stiver, N.W., 1981, Letter to James F. Davis, State Geologist, November 9, 1981, from the Acting Director, Contra Costa County Office of Emergency Services, concerning a preliminary version of the Earthquake Planning Scenario for highways and airports.

Troup, V.B., 1971, Soil test holes: Airport Department, City of San Jose, California (Blueprint of airport layout and analyses of 150 soil borings).

Troup, V.B., 1981, Letter to James F. Davis, State Geologist, December 2, 1981, from the Deputy Director, Airport Planning & Development, Airport Department, City of San Jose, concerning a preliminary version of the Earthquake Planning Scenario for highways and airports.

U.S. Geological Survey, 1981, Scenarios of possible earthquakes affecting major California population centers, with estimates of intensity and ground shaking: Open-File Report 81-115, p.

Walford, J.M., and Kermit, M.L., 1981, Letter to James F. Davis, State Geologist, November 13, 1981, from the Public Works Director and Deputy Public Works Director, Contra Costa County Public Works Department, concerning preparedness of Buchanan Field in the event of a major earthquake on the San Andreas fault.

Webster, D.A., 1973, Map showing areas bordering the southern part of San Francisco Bay where a high water table may adversely affect land use: U.S. Geological Survey Basic Data Contribution 61 (Miscellaneous Field Studies Map MF-530).

Woolfe, D.A., and others, 1975, Seismic and safety elements of the general plan: San Mateo County City-County Planning Task Force Report, Volume Two: Technical supplement (draft), 108 p.

Youd, T.L., and Hoose, S.N., 1978, Historic ground failures in northern California triggered by earthquakes: U.S. Geological Survey Professional Paper 993, 177 p.

APPENDIX

Rossi-Forel Scale,  
Modified Mercalli Scale,  
and Richter Scale



## EARTHQUAKE-MEASURING SCALES

### ROSSI-FOREL INTENSITY SCALE

The first scale to reflect earthquake intensities was developed in the 1880s by de Rossi of Italy and Forel of Switzerland. This scale, with values from 1 to 10, was used for about two decades. The most commonly used form of the Rossi-Forel (R-F) scale reads as follows:

- 1\* Microseismic shock. Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- 2 Extremely feeble shock. Recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- 3 Very feeble shock. Felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- 4 Feeble shock. Felt by persons in motion; disturbance of movable objects, doors, windows, cracking of ceilings.
- 5 Shock of moderate intensity. Felt generally by everyone; disturbance of furniture, beds, etc., ringing of some bells.
- 6 Fairly strong shock. General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.
- 7 Strong shock. Overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- 8 Very strong shock. Fall of chimneys; cracks in the walls of buildings.
- 9 Extremely strong shock. Partial or total destruction of some buildings.
- 10 Shock of extreme intensity. Great disaster; ruins; disturbance of the strata, fissures in the ground, rock falls from mountains.

---

\* Although the convention is to use Roman numerals for intensity, in this report we have employed arabic characters on the map and thus have adopted them in the text.

## MODIFIED MERCALLI INTENSITY SCALE

A need for a more refined scale increased with the advancement of the science of seismology, and in 1902 the Italian seismologist, Mercalli, devised a new scale on a I to XII range. The Mercalli scale was modified in 1931 by American seismologists Harry O. Wood and Frank Neumann to take into account modern structural features. The Modified Mercalli (MM) scale reads as follows:

- I Not felt except by a very few under especially favorable circumstances.
- II Felt only by a few persons at rest, especially on upper floors on buildings. Delicately suspended objects may swing.
- III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
- IV During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
- VI Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
- IX Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

- X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
- XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

The Modified Mercalli intensity scale measures the intensity of an earthquake's effects in a given locality, and is perhaps much more meaningful to the layman because it is based on actual observations of earthquake effects at specific places. It should be noted that because the data used for assigning intensities can be obtained only from direct firsthand reports, considerable time--weeks or months--is sometimes needed before an intensity map can be assembled for a particular earthquake. On the Modified Mercalli intensity scale, values range from I to XII. The most commonly used adaption covers the range of intensity from the conditions of "I--not felt except by very few, favorably situated," to "XII--damage total, lines of sight disturbed, objects thrown into the air." While an earthquake has only one magnitude, it can have many intensities, which decrease with distance from the epicenter.

CORRELATION OF MODIFIED MERCALLI AND ROSSI-FOREL  
SEISMIC INTENSITY SCALES

To convert from R-F to MM, the following table may be useful:

R-F	1	3	5	7.75	8.75	9.5	10
MM	I	III	IV-V	VI	VIII	IX	X-XII

PHYSICAL SCIENCES LIBRARY  
 UNIVERSITY OF CALIFORNIA  
 DAVIS, CALIFORNIA 95618

## RICHTER MAGNITUDE SCALE

The Richter magnitude scale, named after Dr. Charles F. Richter, Professor Emeritus of the California Institute of Technology, is the scale most commonly used, but often misunderstood. On this scale, the earthquake's magnitude is expressed in whole numbers and decimals. However, Richter magnitudes can be confusing and misleading unless the mathematical basis for the scale is understood. It is important to recognize that magnitude varies logarithmically with the wave amplitude of the quake recorded by the seismograph. Each whole number step of magnitude on the scale represents an increase of 10 times in the measured wave amplitude of an earthquake. Thus, the amplitude of an 8.3 magnitude earthquake is not twice as large as a shock of magnitude 4.3, but 10,000 times as large.

Richter magnitude can also provide an estimate of the amount of energy released during the quake. For every unit increase in magnitude, there is a 31-fold increase in energy. For the previous example, a magnitude 8.3 earthquake releases almost one million times more energy than one of magnitude 4.3.

A quake of magnitude 2 on the Richter scale is the smallest quake normally felt by humans. Earthquakes with a Richter magnitude of 7 or more are commonly considered to be major. The Richter magnitude scale has no fixed maximum or minimum; observations have placed the largest recorded earthquakes in the world at about 8.9, and the smallest at -3. Earthquakes with magnitudes smaller than 2 are called "micro-earthquakes." Richter magnitudes are not used to estimate damage. An earthquake in a densely populated area, which results in many deaths and considerable damage, may have the same magnitude as an earthquake that occurs in a barren remote area, that may do nothing more than frighten the wildlife.



APR 26 1

AUG 26 1